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NATURAL RESISTANCE TO INFECTIOUS DISEASE AND ITS REINFORCEMENT.[1]

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COMMON observations early indicated that individuals of all animal species, and of the human species especially, were very unequally subject to disease. This elementary fact is impressed every day upon the thoughtful and has been, from the earliest times, the object of much ingenious speculation. Even to-day, and in spite of the acquisition of a wealth of new facts in physiology and pathology, we are not able to define fully the conditions that make for or against disease. However, the new knowledge which has been acquired enables us to see much more deeply and clearly into the complex mechanisms of disease than could be seen half a century ago; but unfortunately our insight has not been strengthened as regards all diseases, but almost exclusively in relation to the infectious diseases. In respect to the other class, or non-infectious or chronic diseases, among which are Bright's disease, vascular disease, malignant tumors, the gains in fundamental knowledge are far less great.

It may be axiomatic to state that all actual progress in unraveling the complicated conditions of disease depends upon precise knowledge of its underlying causes; and yet in an age in which comparative ignorance still requires that a certain amount of practise shall be empirical, it is well to bear in mind this notion, so that what is undertaken through knowledge may be kept distinct from what is adventured through ignorance. It has been to the lasting credit of the medical profession of an early period, when actual knowledge of the underlying causes of disease had not, and in the then state of development

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of the physical sciences could not, have yielded a single concrete fact, that one method—vaccination—and the most perfect one yet discovered of preventing a disease, and two drugs—quinine and mercury—specific for two other infectious diseases, should have been found and so successfully applied. But in contrast to this slow, painful and halting advance in practical means for the relief of suffering, is to be placed the body of robust facts, acquired in a quarter of a century, during the present or bacteriological era in medicine, which enables us to view in some measure the mechanisms of disease and defense against it, and which has pointed the way to efficient modes of prevention, and, in a few brilliant instances, to the production of biologically perfect means of combating certain infectious maladies. To produce a means, as has been done through the perfection of curative sera, that shall strike down myriads of living parasitic organisms, within the interior of the body, amid millions of sensitive and even sentient cells of the organs, without inflicting on them the smallest injury, is indeed a great accomplishment. And if I am successful to-day in placing before you the main facts, now revealed, of the body's manner of defense to parasitic invasion, you will, I think, come to see that it has been by imitating nature's methods and by augmentation of the natural forces of defense, that good has been achieved.

The facts laboriously acquired, on which this presentation will rest, have been drawn from the study of spontaneous disease—so-called natural disease—among man and animals, and from experimental diseases produced in animals. I need scarcely point out that there is really no unnatural form of disease any more than there is a really natural one; in all instances we are dealing with natural laws of health and disease, the difference merely being that in one case we are often ignorant of the time and manner of entrance of the infecting germs into the body, and in the other they are purposely introduced, in a predetermined efficient manner, in a pure state into the animal body. Since we are so often ignorant of the precise manner of ingress of the germs in the non-experimental forms of disease, we conclude from the identity of the conditions present in the experimental and non-experimental forms of the disease, that in effect they are identical. This power exactly to reproduce at will, by pure bacterial cultures, infectious disease in animals has been of inestimable benefit in investigating disease.

To escape disease is not merely to remain without the zone of influence of the germs of disease. To do this in all cases is impossible, because with certain germ diseases—tuberculosis, for example—the germs are ubiquitous; and with several other diseases the germs are constant if not naturalized inhabitants of the body. Thus we carry on our skin surfaces constantly the germs of suppuration; on the mucous membranes of the nose and throat the germs of pneumonia, and sometimes those of diphtheria, tuberculosis and meningitis. The intestinal

mucous membrane supports a rich and varied bacterial flora among which are several potentially harmful species and sometimes, even under conditions of health, the bacilli of typhoid fever, of dysentery, and in regions in which cholera is endemic, or during its epidemics, of cholera bacilli.

It is obvious, therefore, that it is practically impossible to escape the dangers of bacterial infection, and withdrawal absolutely from other human beings and from all human habitations would be powerless to accomplish this result. It is equally obvious that with such constant and universal exposure to bacterial infection the body must, for the greater part, easily defend itself against this class of its enemies. It is now known that this defense is not merely by exclusion of the bacteria from the interior of the body, although in itself this is an important means of protection for which special mechanisms are provided, but that constant small escapes of bacteria into the blood are taking place from the mucous membranes chiefly, and that there rarely ensues disease from this cause.

On the other hand, there is another class of disease germs that do not regularly inhabit the body and whose influence is occasional only. Some of these germs are exquisitely infectious, as, for example, those causing small-pox, measles and scarlet fever; and others require an intermediate agency to inoculate them as in malaria, yellow fever, and possibly bubonic plague. And yet, excluding small-pox, which in ante-vaccination days overlooked few if any persons in infected regions, a great diversity of susceptibility to infection has been noted again and again among exposed persons and animals. This variability of infectivity affects difference in species, race and individuals and constitutes one of the fundamental problems of disease. Certain diseases are naturally limited to certain species and can not at all, or can only with great difficulty, be transferred to another, although related, species; other diseases appear among several species widely separated from each other; still other diseases choose by preference or are quite restricted to certain breeds of a species; and finally, individuals of a homogeneous species exhibit wide differences of susceptibility to infection. A worked-out theory of infection to and immunity from disease would include and explain, all these, and many more, diversities which have been observed. I need not offer an apology for this at present unattained ideal.

It was early apparent that bacteria must sometimes escape into the blood and yet that infection did not follow. It was observed that frequently at death the interior of the body was free of bacteria and might remain so for many hours and until signs of putrefaction began to be apparent. The deduction from this observation was to the effect that the blood and organs must protect themselves during life and for a period after death from bacterial development. The remarkable antibacterial power of the blood was demonstrated directly by injecting

putrescent fluids into the veins of rabbits and noting that not only might they survive the infections and remain quite normal, but that the blood drawn soon after the injection was made need not, when carefully collected, undergo putrefaction. This fundamental experiment, performed before pure cultures of bacteria were available, left no doubts that the body possesses internal means of ridding itself of large numbers of bacteria.

It is apparent that the body possesses two possible distinct ways of freeing itself of these bacteria: it might remove them through the excretory organs—the kidneys or liver; it might rid itself of them by destroying them inside the body. It was with the rise of modern bacteriology that proof was brought that the blood and certain other body fluids—peritoneal, pleural, pericardial transudates—possess a remarkable power of destroying bacteria. This power resides in shed blood, in the other fluids withdrawn from the body, and even in the fluids deprived of all their natural cellular constituents. Here was then a concrete fact: the fluids of the interior of the body are capable of killing large numbers of bacteria. It could now be shown that the bacteria introduced in large numbers into the blood of a living animal are not excreted but are destroyed within the body. This power of the blood is, however, not indefinite and is not exercised equally against all kinds of bacteria. Even with bacteria that readily succumb a very large number may exceed the blood's capacity to destroy, so that survival and multiplication would result; and certain bacterial species proved highly resistant to this blood destruction. Moreover, it was observed that the blood of all animals tested did not produce the same effects on given kinds of bacteria, that this power to destroy bacteria was lost spontaneously in a few days by the fluids removed from the body and was destroyed immediately by a temperature of 60° C. It is, therefore, a highly labile quality.

Apparently the way was opened up for the detection of the conditions which underlie infection and immunity and the various peculiarities determined by species, race and individual. Unfortunately, there proved to be no sharp relation between the bactericidal powers of shed blood and immunity from or susceptibility to infection. And important as these blood-phenomena proved to be, in accomplishing protection from infection, they do not in themselves account for all observed conditions.

The factors upon which the bactericidal properties of the blood depend have now been clearly ascertained. The chief substance has been called alexin or defensive substance, but in reality the alexin is a compound and consists of a sensitive body—complement—and a more stable substance—intermediary body. Bacteria are killed and disintegrated when the intermediate body can attach itself to them and bring them under the influence of the complement—a digestive enzymotic element, to which the intermediary body also attaches itself.

Moreover, it is now quite certain that of the two principles the intermediary body alone is a fixed, native element of the blood plasma, and the complement is subject to considerable fluctuations in quantity. The origin of the intermediary body has not been determined, while it is quite established that the complement is yielded by the white corpuscles, or leucocytes, of the blood. This matter of the origin of the complement is very important because the protective value of the blood fluid is determined by the quantity of complement available at any one time and not so much by the more constant intermediary body which is usually in excess of the complement. The complement would appear to arise from the leucocytes partly as a secretion; but the quantity derived in this way would not appear to be considerable. It also arises from leucocytes which are brought by any cause to degeneration and disintegration, and this would seem to be a richer source than the other. Leucocytes are constantly being worn out by physiological use and as constantly yielding up their complement to the blood as they go to pieces. It would appear, then, that the very essential complement which exists in the circulating blood and passes from the blood into the lymph and serous cavities, will be more or less determined in quantity by the number of blood leucocytes and the conditions to which they are exposed, and as they are brought to slower or faster degeneration; and it is extremely probable that the secretion of complement is influenced also by the nature of the stimuli to which even the living leucocytes are exposed. It has been shown beyond peradventure that the blood plasma contains less complement than blood serum, as would now be expected since the origin of complement from degenerating leucocytes has been abundantly shown, and because in the clotting of the blood the leucocytes are so greatly disintegrated. But I do not think that even the most ardent adversaries of the view that the fluids of the interior of the body do not exert direct bactericidal effects, have been able to show that the plasma contains no complement. The complement is such a labile body that doubtless it is constantly used up physiologically and must therefore as constantly be renewed, and it is highly probable that the balance between production and destruction may not always be maintained, whence a considerable fluctuation may occur even in health. Whether the fluctuations ever synchronize with intending infections in such a manner as to promote them is not really known, but is not impossible.

It is, however, patent that the naturally operative defensive mechanisms against bacterial invasion must contain other factors than these humoral ones. We are all now prepared to admit that in the phagocytes, or the devouring white corpuscles of the blood, the body possesses another defensive system of high efficiency. The motile nature of these cells and their presence in the circulating blood accord them a high degree of mobility, so that they can be quickly dispatched to any part of the body threatened by invaders, and are hardly behind the fluids of

the blood in this ability to be massed or delivered where needed. The phagocytic mechanism of defense operates through all the orders of the metazoa; and while it can hardly have been developed originally as a protective system against parasites, and doubtless represents a mechanism for disposing of effete and useless particulate matter in the body by a process of intracellular digestion, yet it has reached through evolutionary selection a high state of perfection and must have exercised no small influence in protecting from extinction certain living species.

There is good reason to believe that in the final disposal of bacteria intruded into the body the phagocytes play the terminal rôle: *i. e.*, under favorable conditions they are attracted through chemical stimuli furnished by the bacteria to which they respond to englobe them, after which the bacteria are often disintegrated. But there is equally good reason to believe that, with few exceptions, this engulfing can not take place until the bacteria have been acted on by certain plasmatic constituents that prepare the bacteria to be taken into the body of the phagocytes. The further the phenomena of bacterial destruction in the body are probed the more certain does it become that there is no single and uniform process of their disposal. The humoral doctrine of bacterial destruction contains much of fact, the phagocytic doctrine much of fact, and it is quite certain that the practical defensive activities of the body constantly imply the use of both mechanisms.

And when we push the analysis of the manner in which bacteria injure the body and enumerate the various bactericidal substances which have now been determined as existing in the plasma and in the cells, we find that this interaction must be supposed to take place. Plasmatic bactericidal action and phagocytic inclusion are cooperative functions; plasmatic antitoxic action and phagocytic detoxication are cooperative functions; plasmatic opsonization and phagocytic ingestion are complemental functions; plasmatic agglutination and phagocytic engulfing are also complemental, although less essential functions. And although in intending infections the toxic action of the bacteria to be dealt with is less a matter of great consequence, yet in principle the disposal of a few bacteria is not different from the disposal of many; and in dealing with the poison or toxic elements of bacteria, the plasma possesses distinct power of direct neutralization as the phagocytes possess distinct ability to transform poisonous into non-poisonous molecules.

I desire now to refer again to the subject of racial and species immunity for which the humoral factors of bacterial destruction afforded an imperfect explanation, in order that I may point out that the introduction of bacteria, incapable of causing infection, into immune species is followed by immediate phagocytic ingestion and destruction of the microorganisms. The rapidity and perfection of the phagocytic reaction in insusceptible animals are very impressive and might readily lead to the decision that they suffice to explain the resistance or

immunity. However, the matter does not permit of such summary disposal, since there appear to be other factors that enter into the phenomena. The frog that does not become tetanic when inoculated with tetanus bacilli or poison, develops tetanic spasms when the temperature is raised somewhat; the hen that does not respond to an anthrax inoculation develops the infection when the temperature is lowered somewhat. Even for the final ingestion of bacteria by the phagocytes of alien and insusceptible species the plasma principles are required.

Undoubtedly the phenomena of racial and species immunity are affected by phagocytosis. But our present knowledge does not justify us in disregarding other possible and contributing agencies. We are still so little informed of even the grosser features of the body's metabolism that it would be premature to deny to it influence on susceptibility to infection. Between the metabolism of birds and mammals there is such wide disparity that an influence could easily be conceived; but the metabolic disparity is less between the herbivora and carnivora, and still less between some closely related species which yet show marked differences in susceptibility to bacterial infection; and as between individuals of the same species it could only be the finer intramolecular variations that conceivably could come into play.

Although the properties of the defensive mechanisms of the blood have not been exhausted, yet they have been defined in such detail as to suffice for the moment and to permit us to turn attention, for a brief space, to some of the properties of the intending invading bacteria. It is matter of common experience, which each of us has suffered, that the elaborate mechanisms provided for our protection from bacterial infection do not always suffice, and now it becomes necessary to explain why they do not. In the first place, there are very great differences between the bacteria which seek to enter the body. Some species are never very harmful and are readily combated, excluded or destroyed; other species often possess only a moderate degree of virulence or potential power of doing injury and can also, as a rule, be overcome; while these second species sometimes acquire such highly virulent or invasive powers that the defenses prove quite inadequate to exclude or combat them. During the prevalence of great bacterial epidemics it is probable that this factor, virulence, plays a considerable rôle. Of course in epidemics the bacterial causes are by the exigencies of the situation more widely diffused than at other times, so that more individuals come under their influence; but with even such a common bacterium as the diplococcus which causes pneumonia and the bacillus which produces influenza, there arise conditions in which severe and often very extensive outbreaks, or localized epidemics, occur which are probably to be attributed to an accession in virulence of these germs, although the precise causes leading to the increase may not be discovered.

Now this quality of virulence, which is often evolved so quickly

and apparently so mysteriously is expressed biologically in various ways besides in that of greater infective power: virulent bacteria may prove incapable of being charged with opsonin so that they can not be ingested by phagocytes; they may show unusual power to resist plasma or serum destruction; they may drive away or repel or act negatively in respect to chemical attraction on the phagocytes; and being thus unopposable they tend to multiply quickly and with little restraint and thus still further to break down and render ineffective the normal defensive mechanisms, and ultimately to damage seriously the sensitive cells of the organs. This constitutes disease.

Another power resides in the body that should be regarded, namely, the power to neutralize or destroy poisons as distinct from parasites; for the body is exposed to the deleterious action of poisons generated by living parasites that do not themselves penetrate within the body. Some of these poisons are generated away from the body, as is the case with certain food poisons; some by bacteria in the intestinal canal that do not seek to invade the blood; some by bacteria, like the diphtheria bacillus, that first kill tissue, usually of the mucous membranes, and then develop in the dead tissue and send the poison into the body. And besides this every bacterial disease resolves itself ultimately into a process of poisoning—of intoxication. In typhoid fever, in pneumonia, in meningitis and in the multitude of other bacterial invasive diseases of man and the lower animals, the severe symptoms are caused by the poisons liberated through disintegration of the invading bacteria which, however, continue by multiplication to recruit their numbers.

The condition of susceptibility to poisons varies with different races and species, very much as bacterial susceptibility does. The cold-blooded animals are indifferent to poisons that are very injurious to warm-blooded animals, but not all cold-blooded animals behave alike. Tetanus toxin is alike innocuous for the frog and the alligator; but by raising the temperature artificially the frog develops tetanus, but the alligator does not. Sometimes the effects depend merely upon the mode of entrance of the poison into the body. Tetanus toxin, diphtheria toxin and snake venom have no effect on mammals when swallowed unless the intestinal epithelium has been injured. These poisons can not pass through the epithelium to reach the blood, where alone they can exert their action. The toxin of the dysentery bacillus passes readily in the rabbit from the blood into the intestine, which it injures, but can not pass from the intestine into the blood. Tetanus toxin can be injected into the circulation of the hen but does no harm. Injected into the brain it produces tetanus. Introduced into the blood it remains there for many weeks, hence the failure to act can not be due to destruction, but probably is due to inability to pass through the blood vessels in order to reach the cells of the central nervous system in a sufficient state of concentration. The physiological state of the animal also exerts an influence: certain hibernating species are sus-

ceptible to tetanus poison in the summer but not during the winter sleep. There exist, therefore, different mechanisms for excluding poisons from the sensitive and reacting cells and among them are certain quantities of neutralizing, or antitoxic substances, normally contained in the blood. We know at least one such definite antitoxin, namely, the diphtheria antitoxin, which exists in minimal quantities in the blood of man and the horse.

The absence of numerical relation between the mechanism which destroys bacteria and neutralizes poisons sometimes works sad havoc for the body. The two capacities may differ naturally or are enhanced in different degrees by artificial means. The matter is one of great importance because almost without exception all bacterial diseases are examples of poisoning. The mechanical obstructions produced by the bacterial bodies are relatively unimportant. The body is more readily defended from the invasion of bacteria, with very few exceptions, than from the effects of their poisons. The capacity to dispose of typhoid and cholera bacilli is more easily produced than the power to neutralize or otherwise render innocuous the poisons liberated by the dissolved bacilli. It is precisely because we have not yet learned how to overcome this class of bacterial poisons within the body that we have not mastered the bacterial diseases as a whole. There are, however, certain bacterial poisons for which adequate antidotes are readily produced, thus, for example, for the diphtheria, tetanus, botulism and possibly the dysentery poisons. Here the poisons can be more easily neutralized than the bacilli can be got rid of, but by neutralizing the poisons we succeed in arresting the multiplication of the bacteria and often in curing the disease.

The normal body possesses a mean resistance to bacterial invasion and to bacterial poisoning which, while somewhat fluctuant, is of high value except under certain exceptional conditions in which infection readily develops. We know that certain general states of and influences exerted on the body are associated with a rise or a fall of this mean value. But we are not equally informed of the physical basis of this rise and fall. This particular topic is peculiarly difficult because of the large numbers of factors which enter into it. We know from observation that proper clothing, wholesome food, good hygienic surroundings, avoidance of over fatigue and of depressing psychic impressions, and that physical care of the body, all contribute toward maintaining health as the reverse conditions predispose to establishing disease. In seeking the physical basis of this difference we must avoid confusing cause with effect. Good hygienic surroundings may act chiefly by excluding the sources of infection rather than by enhancing resistance. Yet there is experimental as well as observational foundation for the belief in these general influences to affect the disposition to acquire or escape infectious disease. Animals which are made to fast, to over-exercise, are made anæmic, are given excessive quantities of

alcohol and other poisons, or are exposed to abnormal cold by shaving of the skin, are more subject to certain infections than animals not so treated. If, now, it were found that the blood factors governing resistance fluctuated with these influences, became smaller and less conspicuous when the influences were bad and larger and more efficient when the influences were good, we should then have established an important concrete fact.

But the alexinic activity of the blood varies normally within such wide limits that only maximal changes could be regarded as significant, and it appears that it is only as the fatal termination of certain severe infections are reached—such as experimental anthrax and pneumococcus infections, for example—that the alexinic power falls greatly or disappears altogether. The determination of phagocytic activity outside the body has not thus far been carried out in such a manner as to indicate a functional depression which either precedes immediately or develops in the course of severe infections; although certain infections which take a severe course are characterized by a persistent reduction in the number of leucocytes in the circulating blood. This latter phenomenon must, however, probably be regarded as an effect and not as the cause of the infection. There is, however, known at least one example where paralysis of the phagocytes leads to a fatal infection under conditions in which the normal phagocytes are entirely competent to prevent infection. If to a guinea-pig a small dose of opium be administered and this is followed by the injection of a non-lethal quantity of a culture of the cholera bacillus, death will ensue because the sensitiveness of the phagocytes to the chemical stimulus exerted by the cholera poison has been diminished by the narcotic influence of the opium.

The mean phagocytic value of the blood can, however, be definitely raised by certain agencies, that are at the same time and through the rise in the number of phagocytes produced, useful in warding off and sometimes even in overcoming infection. The means employed to bring about an increase of leucocytes, or to establish a hyperleucocytosis, suffice to maintain the high value for short period relatively only, unless the stimulus is frequently repeated. A cold bath, a sun bath, the injection into the circulation of a number of simple chemical substances—peptone, albumose, nucleinic acid, spermin, pilocarpine—are all followed under physiological conditions by hyperleucocytosis and by a temporary state of increased resistance to bacterial invasion. Moreover, in certain experimental infections, at least, there can thus be aroused a heightened power to overcome established infections—those caused, for example, by the cholera, meningitis and pneumococcus germs. Perhaps the most striking example of the protective influence of hyperleucocytosis is afforded by the experimental infection described under the name of cholera peritonitis of the guinea-pig. If a fatal quantity of cholera germs be injected into the peritoneal cavity of a

guinea-pig, symptoms of poisoning quickly set in and death results in a few hours. A study of the conditions present in the peritoneal cavity shows that the bacteria have developed freely, that some have been broken up and disintegrated, and that very few preserved phagocytes can be found. Examination of the blood reveals that the number of leucocytes in the general circulation has been reduced; and all the evidences point to the conclusion that not only has phagocytosis not taken place, but that there has been a general destruction of leucocytes produced by the cholera poison. If, however, there be introduced into the peritoneal cavity of a guinea-pig twelve to twenty-four hours prior to the inoculation of the cholera bacilli, a small amount of sterile salt solution, or bouillon, or one of the other chemicals mentioned, which procedure will bring into the peritoneum a considerable number of leucocytes at the same time that it causes a rise of leucocytes in the circulating blood, then the cholera germs are quickly taken up by the phagocytes, multiplication is prevented, and the animal escapes severe illness.

The value of hyperleucocytosis as a defensive measure against infection must, probably, always remain greater than its value as a cure for established infection. There are several reasons that make this conclusion probable: the capacity of the blood is increased in the direction of destroying bacteria without being augmented at the same time in the direction of neutralizing bacterial poisons; the organism that is already severely poisoned by infection reacts less certainly to the chemical agents that provoke hyperleucocytosis than the uninfected organism. And yet we may see the operation of the benign influence of hyperleucocytosis, associated with an increased passage of alexin-containing lymph through the vessels, upon certain local infections at least, in the results of measures that determine an augmented supply of blood to a diseased part; in the mechanical hyperæmias produced through posture or superheated air; the influence (in part) of tuberculin injections; and the effects of poultices and embrocations, of counter-irritants, and of certain of the phenomena of local inflammation.

The facts at our command point to the great potential power of the normal organism to resist infection and indicate that the normal body possesses the capacity, on demand, to increase this power beyond the mean value, chiefly by opposing intending infection by hyperleucocytosis and also, probably, by the strengthening of its plasmatic defensive action through the additional soluble alexin substances thrown off by the augmented leucocytes. This defensive mechanism acts in the same manner on all bacterial invaders and is not specially adapted for any one or group of bacteria. The form of activity is strictly non-specific.

Let us now ask ourselves if in overcoming infectious disease, which luckily the organism is frequently able to accomplish, the mechanism put into operation is similar and only more intense than the one we have considered for warding off infection? The answer to this question

is that recovery from infection consists in the bringing into being of a new set of phenomena that gradually reinforce the resistance; that recovery from infection is accomplished through a process of immunization. The evidences of this condition of immunization are found in the appearance in the blood some time between the fourth or fifth to the tenth day of the disease, and somewhat later than they have appeared in the spleen and bone marrow, of chemical substances which are directed in a specific manner to the neutralization of the poisons having been and still being produced by the bacterial causes of the disease, to the destruction of the bacteria themselves either outright by the plasmatic fluid which has now been enriched by a new quantity of intermediary substance of high potency that may bring the bacteria more readily under the dissolving influence of the complement, or by the phagocytes to which they are exposed in greater measure through the production of opsonins of higher strength and stability. As recovery progresses these immunity substances continue to increase until at the termination of the disease they are present in quantities that suffice often, by a passive transfer to another individual, to protect other animals more certainly from an infection, or to terminate abruptly an infection already established in them.

When the infectious disease is the expression not of the combined effects of poison and bacteria but of the poison chiefly which enters the blood, the bacteria remaining without as in diphtheria, then the blood changes characterizing the immune state are simpler and consist in the accumulation there of antitoxins that constitute the most perfect antidote to poisons that are known. The condition of immunity produces no demonstrable change in the properties of the phagocytes through which they are better enabled to overcome the poisonous bacteria. They do become, in course of the immunization, more sensitive to positive chemotactic stimuli; but it is still an unsettled question whether they are altered qualitatively by the immunization, or whether the plasmatic changes do not really react upon them and thus increase their efficiency.

It must now be patent that between what may be termed the process of physiological resistance and what is termed the condition of immunization, a wide distinction exists. The one is non-specific in its action, the other highly specific in its effects; the one is subject to a limited augmentation, the other may be carried to a high degree of potency and perfection; the one often fails to protect the organism in which it is developed, the other suffices to protect both itself and another organism. If therefore we were to be asked in what manner can the animal organism best be reinforced against infection, we should be compelled to answer by passing safely through the infection itself. This conclusion, which has been reached by purely experimental biological methods is supported on every side by common observation and experience with

the acute infectious diseases of which one attack protects from a subsequent attack of the same disease.

It may conduce to clearness if we should enumerate the factors that have been described and assigned on the one hand to natural resistance, and on the other hand to acquired resistance or immunity. We can tabulate the factors in the following manner:

Natural or Physiological Resistance	Increased Natural or Physiological Resistance
Alexin { complement. intermediary body. opsonin. agglutinin.	Alexin { complement, probably increased. intermediary body. opsonin. agglutinin.
Phagocyte.	Phagocyte—increased (hyperleucocytosis).

Acquired Immunity

Complement—probably increased.
Intermediary body—specific one produced.
Opsonin—specific, stabile one produced.
Agglutinin—specific one produced.
Antitoxin { for exotoxin / for endotoxin } produced.
Phagocyte—often increased but qualitatively unchanged.

This tabulation exhibits the distinction between the physical basis of physiological resistance and of the state of immunity. There is another difference between them; any increase that can be called out beyond the mean of physiological resistance is accomplished in a few hours; and having been called out to meet a particular condition of need of the body and the effect having been exerted, it passes off very soon. It is rare that the effect of a hyperleucocytosis can be detected for more than three or four days after it has appeared. The development of the state of immunity, on the other hand, is a slow process relatively and depends upon the setting into motion of certain cell-functions, through which new substances are produced, which, being first retained within the cells producing them, eventually are passed into the blood. Hence it is that these new substances can be detected at an earlier period of the infection in the spleen than in the blood. But once they have been produced, the substances endure either for an indefinite period, or the capacity to produce new ones of the same sort is retained by the organism often for years. The blood may grow weak in the typhoid immunity principle in the course of years following an attack of typhoid fever, or a rabbit immunized with typhoid bacilli may show after a time a great diminution of the blood agglutinins for typhoid bacilli; but the typhoid immunity persists in the one, as in the other minimal quantities of typhoid bacilli will bring out, and without the original delay, a new production of agglutinin that will restore the lost amount.

The facts on immunity which I have presented to you constitute the physical basis, also, of all artificial methods which are being pursued so successfully in preventing certain infections through vaccination, and in curing them through the use of immune serum products. The facts also account in an eminently satisfactory manner for the suppression of small-pox by cow-pox vaccination. The "vaccines" so-called for bacterial diseases, which are, I might say, at present being employed chiefly in protecting animals from epidemic infectious diseases to which they are much exposed, consist for the most part of bacteria either killed outright by heat or chemicals or of bacteria whose virulence has been diminished by special methods of cultivation or treatment. In human beings this method of vaccination has been employed only when large numbers of persons have been exposed to infections from the zone or focus of which they could not be removed, or from which, owing to the peculiar circumstances surrounding the infections, they could not readily or at all be protected by the suppression of the diseased germs at their sources. Thus it has been found advantageous in a few instances to employ vaccination against cholera and bubonic plague, on those especially exposed to these epidemic diseases, and against typhoid fever on troops going in time of war into heavily infected endemic zones of that disease.

In a few instances this method of vaccination has been successfully carried out in animals with infectious diseases in which the germs causing them have not been discovered. Thus it is possible to vaccinate cattle against the destructive rinderpest of Africa, the Philippines and other tropical countries, by employing the bile of animals which have succumbed to the infection, which contains the parasite of the disease somewhat modified by certain immunity principles contained within it along with parasites. In fact, this method of conjoint vaccination with the parasite of the disease and the blood containing immunity principles is one that offers a considerable field of practical application. On the one hand, there is accomplished a passive immunization of the body that becomes operative immediately and, on the other hand, a vaccination that after the usual interval leads to the production of a state of active immunity that rises to a higher level and is far more enduring than the passive state.

Incidentally we have discovered from this process of mixed or conjoint vaccination that immune sera prepared for bacteria or other parasites which are not toxin producers in the manner of the diphtheria bacillus, but which contain endotoxin, act not especially by neutralizing toxins, or by destroying outright the bacteria, but by exercising an efficient protective control over the injury which these parasites or their poisons tend to inflict on certain sensitive body cells. For example, if cattle are inoculated on one side of the body with virulent blood from animals dying of rinderpest, and on the other side with blood serum taken from animals that have recovered from the

disease and subsequently have had their immunity intensified by injections of highly virulent blood, the cattle so vaccinated will develop rinderpest in a mild form and will subsequently on recovery be also immune; and yet during the process of immunization their blood contains highly virulent parasites so that if a little of it be introduced into non-protected and healthy cattle, they will be given rinderpest and will die of it.

The reaction of the body to the bacterial vaccines injected is out of proportion to the quantity of culture introduced. Thus two milligrams of dead cholera bacilli injected under the skin of human beings will yield enough of the specific immunity substance for these bacilli to bring about the destruction of 60,000 or more milligrams of the culture. There can be, therefore, no direct transformation of the cholera bacilli into immunity bodies, but they must exert a stimulus on certain cell-functions through which the immunity principles are produced; and the quantity of their formation depends not on the weight of crude bacilli introduced, but on the strength of the stimulus impressed upon the sensitive cells to which they react in a specific and remarkable manner.

Is it possible in the course of an established infection to reinforce the resistance of the body? I have already stated that it is not practicable to bring out at the height of an infection an efficient heightened reaction of physiological resistance; but from this it does not follow that under these conditions a special form of immunity reaction may not be elicited. The tuberculin reaction, or that part of it which is specific, may be cited as an example of this kind of reinforcement; and whatever there is of value in the treatment of infectious diseases by means of dead cultures of their specific bacteria—"vaccines" so-called —must be of the nature of an intensified immunity reaction. What is sought to be accomplished in the latter case is the formation in certain uninfected localities—in the subcutaneous tissues, for example—of immunity principles that afterwards by escaping into the blood shall assist in the termination of an infectious process situated elsewhere in the body. Such local foci of immunity as it is designed to create in the subcutaneous tissue are not unknown. The pleura can be given a local immunity to the typhoid bacilli; the subcutaneous tissue to tetanus toxin, and it is highly probable that the normal resistances exhibited by our mucous membranes to the pathogenic bacteria they harbor are examples of such local immunities.

I fear that I have carried you far afield and into somewhat devious paths of immunity to disease. You will, I know, not complain and hold it to the detriment of medical science, that these paths have not been already converted into fine open roads. But you will prefer to recall how brief is the time since where the paths now are there were only wood and tangle.

SOME PRACTICAL ASPECTS OF GYROSTATIC ACTION

By Professor W. S. FRANKLIN
LEHIGH UNIVERSITY

THE Brennan monorail car and the Schlick device for the prevention of rolling of ships at sea have recently attracted popular attention to the gyrostat, and gyrostatic action has recently become vitally interesting to a large group of men because an automobile-engine fly-wheel shows serious gyrostatic reactions when the automobile rounds a curve rapidly or rises suddenly upon a bump in the road. The following discussion will therefore be welcomed by many readers. Let no one imagine that gyrostatic action is mysterious and difficult to analyze; it is really quite simple[1] and the discussion of Fig. 10 makes this action as clear, physically, as the simple inertia reaction of a heavily loaded wagon or boat. The formula for calculating the numerical value of the torque reaction of a gyrostat, as given at the end of this paper, is simple enough for any one to use.

The rotation of a wheel on an axis is called spin, and the axle upon which the wheel rotates is called the axle of spin. The spin of a wheel may be completely represented in both magnitude and direction by an arrow drawn parallel to the axle of spin, pointing in the direction in which a right-handed screw would travel if turned with the spinning wheel, and having a length which represents the number of revolutions per second of the wheel. Thus, the arrow S,[2] Fig. 1, represents the spin of the wheel WW.

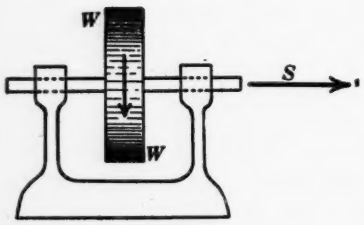


Fig. 1.

Let the arrow S', Fig. 2, represent the spin of a body, imagine a large turning force to act upon the body for a short time, and let the arrow S'' represent the spin which would be produced by the turning force if the body had been initially at rest. The actual resultant spin

[1] When the angular velocity of precession is small as compared with the velocity of spin and when the gyrostat wheel is symmetrical with respect to its axis of spin.

[2] To appreciate the geometrical meaning of the arrows S, ΔS and T in the vector diagrams given in this paper, the reader should thrust his hand in the direction of the arrow head and move the hand as if turning a right-handed screw.

of the body will be represented in magnitude and in direction by the arrow R.[3] That is to say, after the large turning force has acted for a short time the body will be found spinning about R as an axis, and the number of revolutions per second will be represented by the length of R. The geometrical relationship between the arrows S', S'', and R is completely represented in the triangle OMN of Fig. 2, which triangle is shown by itself in Fig. 3.

A turning force is usually called a torque, thus the turning or

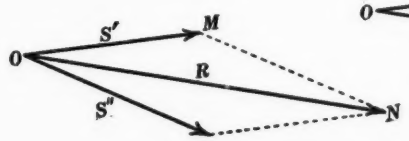


FIG. 2.

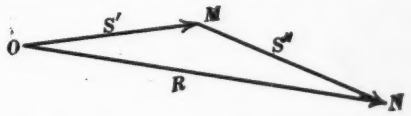


FIG. 3.

twisting force which is exerted upon a screw driver is a torque. A torque may be completely represented by an arrow drawn parallel to the axis of the torque, pointing in the direction in which a right-handed screw would travel if turned by the torque, and having a length which represents the magnitude or value Fl of the torque to scale. Thus the arrow T in Fig. 4 represents the torque due to the two forces FF.

The effect of an unbalanced torque upon a body is to produce a spin-velocity about the same axis as the torque, the amount pro-

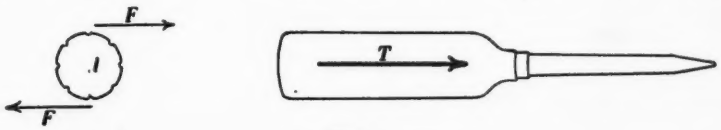


FIG. 4.

duced being proportional to the time the torque continues to act and inversely proportional to what is called the moment of inertia of the body. (*a*) The simplest case is where the axis of the torque is parallel to the axis of already existing spin as shown in Fig. 5, which represents a wheel and axle set spinning by pulling a cord which is wound around the axle. In this case the axle of spin remains stationary, and the magnitude of the spin increases steadily as long as the torque continues to act. (*b*) The general case is where the axis of the torque makes any angle whatever with the axis of the already existing spin. Thus, let the arrow S, Fig. 6, represent the already existing spin of

[3] This proposition is entirely correct if by spin we understand that spin-momentum is meant; the spin-velocity of a body is sometimes greatly complicated by its lack of symmetry, and these complications are ignored in the present discussion.

a body, and let the arrow T represent a torque acting upon the body. Then the arrow ΔS represents the amount of spin produced by T during a short interval of time, and the diagonal arrow S' represents the actual spin of the body after the torque T has acted for a short interval of time.

(*c*) The case where the axis of torque is always at right angles to the axis of spin is the most important case, and this case is exemplified in the ordinary gyrostat, which is a wheel and axle supported in a

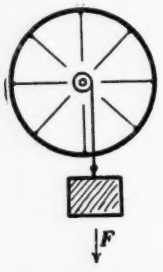


FIG. 5.

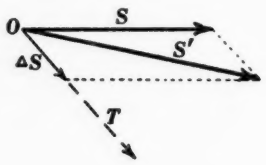


FIG. 6.

movable frame as shown in Fig. 7. *By taking hold of the frame it is impossible to exert a torque upon the wheel except about an axis perpendicular to OS, friction at pivots being ignored.* If the frame be suspended by a string as shown in Fig. 7 (side view), the pull of the earth combined with the pull of the string constitutes a torque as indicated by the arrow T in Fig. 7 (top view). The effect of this torque during a short interval of time is to produce a certain amount of spin, or spin-momentum, ΔS about T as an axis, and the resultant axis of spin

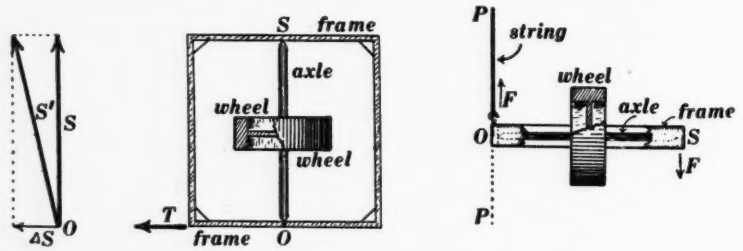


FIG. 7.

becomes S' as shown in the diagram Fig. 7. The unbalanced torque T, due to the weight of the wheel and frame in Fig. 7, causes the frame and wheel to sweep round and round in a horizontal plane about the supporting string as an axis. This kind of motion of an axis of spin due to a torque which is at each instant at right angles to the axis of spin is called *precession,* and the axis PP, Fig. 7, about which the axis of spin rotates is called the axis of precession.

A familiar form of gyrostat is shown in Fig. 8. It consists of a spinning wheel mounted in a metal ring which rests on a pivot O. The pull of the earth on the wheel and ring produces an unbalanced torque about an axis which is at right angles to the axis of spin, and this torque causes the axis of spin to sweep around the pivot O as described in connection with Fig. 7. Precessional motion is illustrated

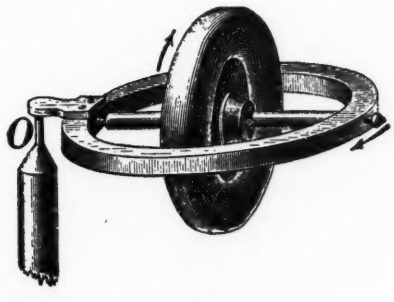


FIG. 8.

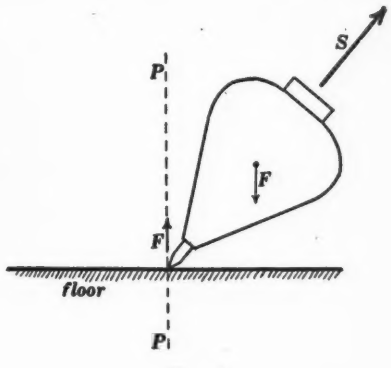


FIG. 9.

in the simplest kind of way by the ordinary top. Fig. 9 shows a top spinning about an inclined axis S. The weight of the top together with the reaction of the floor against the point of the top produces a torque the axis of which is at right angles to the plane of the paper

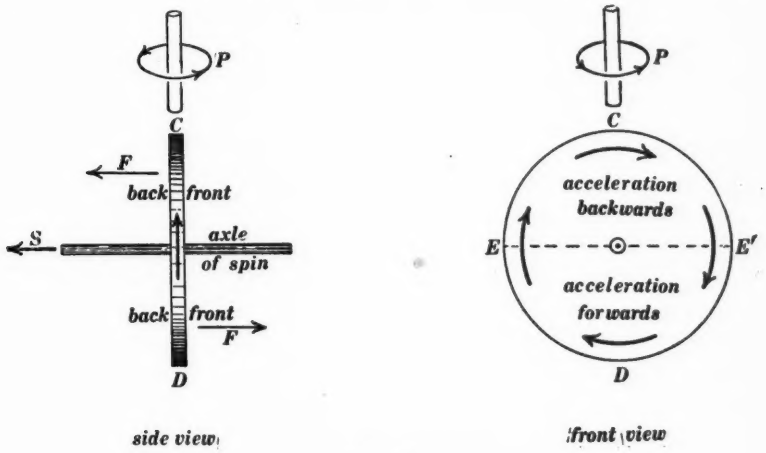


FIG. 10.

in Fig 9, and the effect of this torque is to cause the axis of spin to sweep around the vertical axis PP (the axis of precession).

The above discussion furnishes a sufficient basis for the consideration of the various practical aspects of gyrostatic action, but it is interesting to see how the precessional motion of the gyrostat in Fig.

8 (sweeping of axis of spin about a vertical axis through O) brings about inertia reactions of the various particles of the spinning wheel which keep the wheel from falling under the pull of gravity; it is only necessary to show that to produce precessional motion there must act upon the gyrostat-wheel an unbalanced torque (the torque due to the pull of gravity upon the overhanging frame and wheel in Fig. 8). Fig. 10 represents a disk spinning in the direction of the curved arrows (in the front view), the spin being represented by the straight arrow S in the side view. Imagine the axle of spin to sweep slowly

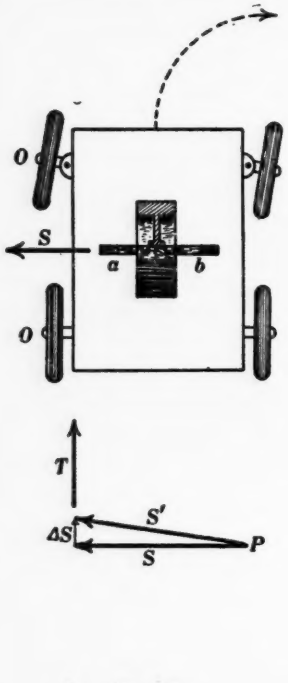


FIG. 11.

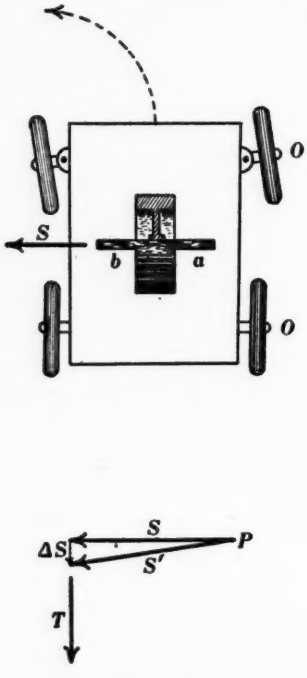


FIG. 12.

around the vertical line CD in the direction of the curved arrows PP. This sweeping of the axle of spin about the line CD constitutes precessional motion, and CD is the axis of precession. Consider the front view of the spinning disk in Fig. 10; every particle in the upper half of the disk has a component of its velocity towards the right, and every particle in the lower half of the disk has a component of its velocity towards the left. After a short interval of time the precessional motion moves the edge E of the disk forwards and the edge E' of the disk backwards in the figure, so that the velocity of every particle in the upper half of the disk is turned slightly backwards and the velocity of every particle in the lower half of the disk is turned slightly forwards, that is to say, every particle in the upper half of the

disk has received a slight backward component of velocity and every particle in the lower half of the disk has received a slight forward component of velocity. Therefore, during the short interval of time, every particle of the upper half of the disk must have been gaining velocity backwards and every particle in the lower half of the disk must have been gaining velocity forwards, so that unbalanced forces must have been pushing backwards on every particle in the upper half of the disk and pulling forwards on every particle in the lower half of the disk, or, in other words, a torque must have been acting about the line EE' as an axis as shown by the two arrows FF in the side view.

GYROSTATIC ACTION OF THE FLY-WHEEL OF THE AUTOMOBILE ENGINE

Figs. 11 and 12 show top views of an automobile, the curved dotted arrows represent the turning of the automobile around a curve, and the

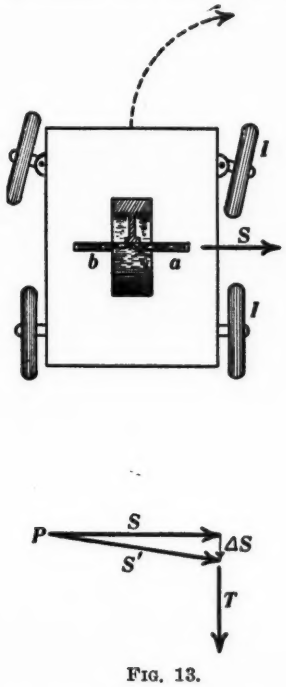


FIG. 13.

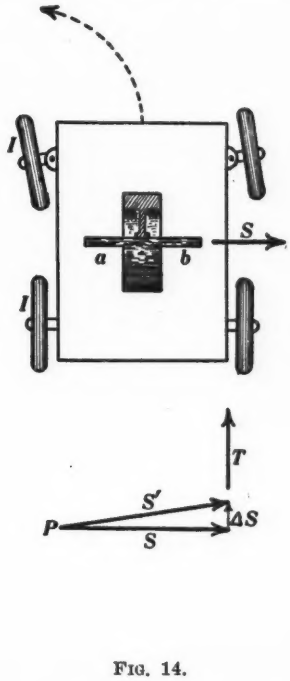


FIG. 14.

straight arrows S represent the spin of the fly-wheel shaft. The arrow S in the vector diagram of Fig. 11 or 12 represents the spin-momentum of the fly-wheel at a given instant, the arrow S' represents the spin-momentum at a later instant, ΔS represents the increment of spin-momentum, and the arrow T represents the torque which must act upon the fly-wheel shaft.

To produce this torque the bearing a must push upwards on the engine shaft and the bearing b must push downwards on the engine

shaft, or, in other words, the engine shaft must push downwards on the bearing *a* and pull upwards on the bearing *b*, so that the gyrostatic reaction of the fly-wheel causes the outer wheels *OO* of the automobile to be pushed against the ground excessively as the automobile turns round a curve.

Figs. 11 and 12 represent the case in which the top of the spinning fly-wheel is moving forwards, and Figs. 13 and 14 represent the case in which the top of the spinning fly-wheel is moving backwards. In Figs. 13 and 14 the gyrostatic action of the fly-wheel causes the inner wheels *II* of the automobile to be forced against the ground excessively, as may be seen by studying the vector diagrams in Figs. 13 and 14.

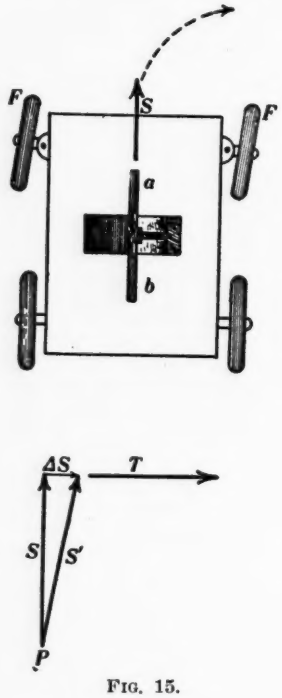


FIG. 15.

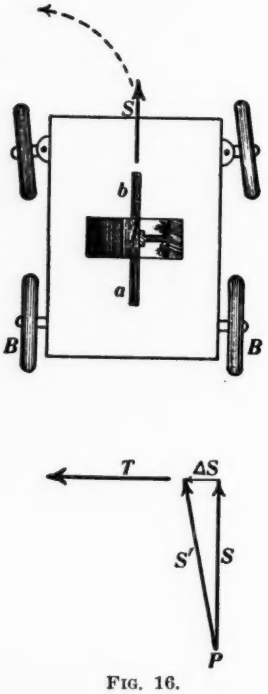


FIG. 16.

Figs. 15 and 16 represent the case in which the fly-wheel shaft is parallel to the length of the car. In Fig. 15 the car is represented as turning to the right, the arrow *S* in the vector diagram represents the spin-momentum of the fly-wheel at a given instant, *S'* represents the spin-momentum at a later instant, ΔS represents the increment of spin-momentum, and *T* represents the torque which must act upon the fly-wheel shaft. To produce the torque *T*, the bearing *a* must push upwards upon the engine shaft and the bearing *b* must push downwards on the engine shaft, or, in other words, the engine shaft must push downwards on bearing *a* and upwards on bearing *b*. Therefore the

front wheels *FF* of the automobile are pushed against the ground with excessive force by the gyrostatic reaction of the fly-wheel in Fig. 15. When the automobile is turning to the left, as shown in Fig. 16, the gyrostatic reaction of the fly-wheel causes the rear wheels *BB* of the automobile to be pushed against the ground with excessive force.

When an automobile runs over a bump in the road, no gyrostatic action is produced if the engine shaft is crosswise of the car, but very severe gyrostatic action may be produced if the engine shaft is fore and aft, as shown in Fig. 17. In the vector diagram of Fig. 17,

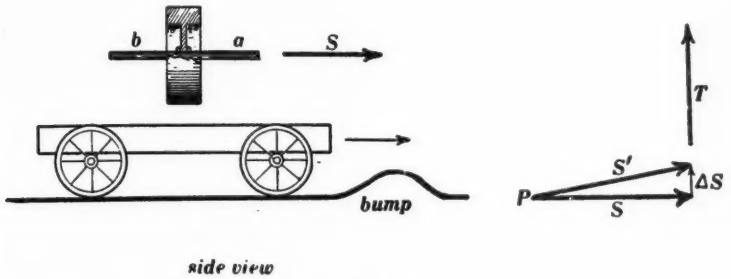


FIG. 17.

S represents the spin-momentum of the fly-wheel at a given instant, *S′* represents the spin-momentum at a later instant, ΔS represents the increment of spin-momentum, and the arrow *T* represents the torque which must act upon the fly-wheel shaft. In order to produce the torque *T*, the bearing *a* must push the front end of the engine axle to the left (with reference to the driver), and the bearing *b* must push the rear end of the engine axle to the right (with reference to the driver); or, in other words, the front end of the engine axle pushes to the right against the bearing *a*, and the rear end of the engine axle pushes to the left against the bearing *b*. Thus, there is a tendency for the front end of the car to be suddenly thrown to the right, when the car rises upon the bump, and the supporting springs of the car body are subjected to a skew action which is apt to break them.

There has been designed and placed upon the market an automobile in which the engine shaft is vertical. This obviates all gyrostatic action in the turning of curves, but it does not reduce the severe gyrostatic reactions when the car runs over a bump.

GYROSTATIC ACTION ON BOARD SHIP

Fig. 18 is a top view of a side-wheel steamer which is represented as turning to the right as indicated by the curved dotted arrow. The arrow *S* in the vector diagram represents the spin-momentum of the paddle wheels and shaft at a given instant, *S′* represents the spin-momentum at a later instant, ΔS represents the increment of spin-

momentum, and the arrow T represents the torque which must act upon the paddle-wheel shaft. To produce this torque the bearing a must push upwards on the crank shaft, and the bearing b must push downwards on the crank shaft, or in other words, the crank shaft must push downwards on bearing a and upwards on bearing b, so that the gyrostatic reaction of the paddle wheels and crank shaft causes the boat to list, sinking the side OO of the boat deeper into the water as it turns round in the direction of the curved arrow in Fig. 18.

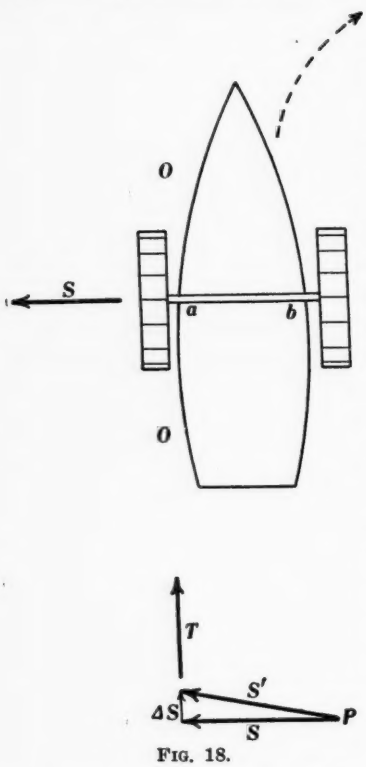


FIG. 18.

Fig. 19 is a side view of a boat driven by a steam turbine and propeller. The most serious gyrostatic action occurs in this case when the boat is pitching violently in a rough sea, and Fig. 19 is intended to represent the bow of the boat as rising as represented by the curved dotted arrow. Under these conditions the arrow S in the vector diagram represents the spin-momentum of the steam turbine and propeller shaft at a given instant, S' represents the spin-momentum at a later

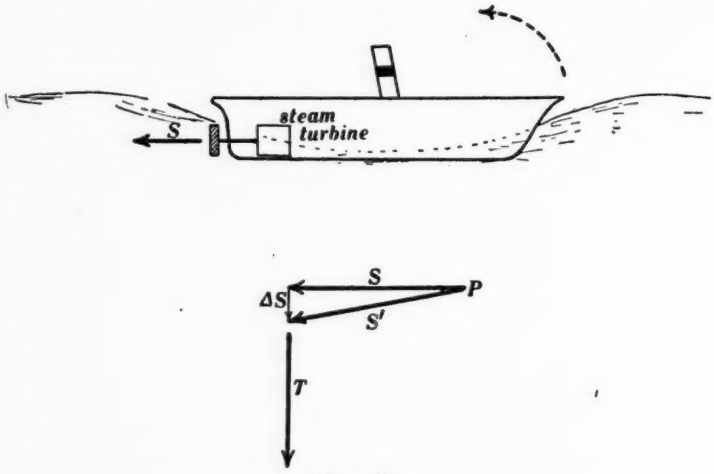


FIG. 19.

instant, ΔS represents the increment of spin-momentum, and the

arrow T represents the torque which must act on the propeller shaft. This torque is exerted upon the propeller shaft by the bearings as indicated by the arrows FF' in the top view, Fig. 20. The high speed and great weight of the rotating parts of a steam turbine represent a very great spin-momentum (arrows S and S' in Fig. 19

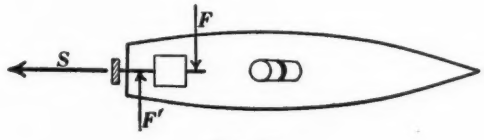


FIG. 20.

very long) so that the increment of spin-momentum ΔS which corresponds to a given angular movement of the ship is very considerable, and the torque T is great. Therefore the forces FF' in Fig. 20 may be very great. These forces are transmitted to the bearings of the propeller shaft through the hull of the vessel from the middle and forward parts of the vessel, and therefore excessive stresses may be brought into existence in the hull. It is supposed that the loss of the

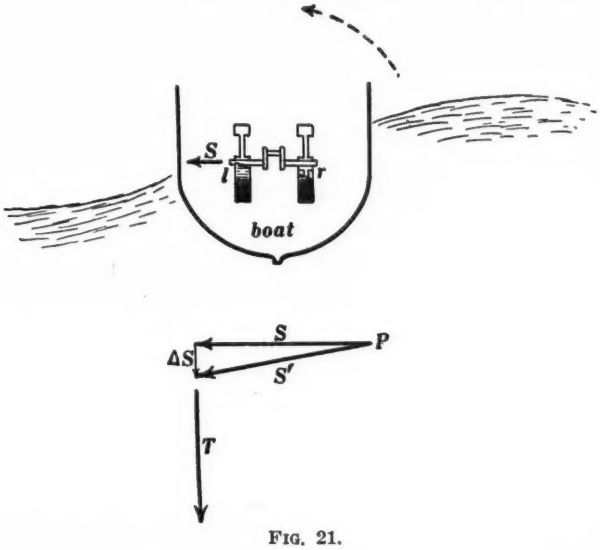


FIG. 21.

British torpedo boat *Viper* several years ago in a rough sea was due to this action.

Figs. 21 and 22 represent the details of the gyrostatic action of a high-speed steam engine, such as is used for driving dynamos on board ship, the shaft of the engine being athwartship. In Fig. 21 the ship is represented as rolling in the direction of the curved dotted arrow, and T in the vector diagram represents the torque which must act upon the engine shaft. The details of this torque action are shown in Fig.

22 where the arrows *FF* in the top view represent the forces with which the bearings must act upon the engine shaft to produce the torque *T*.

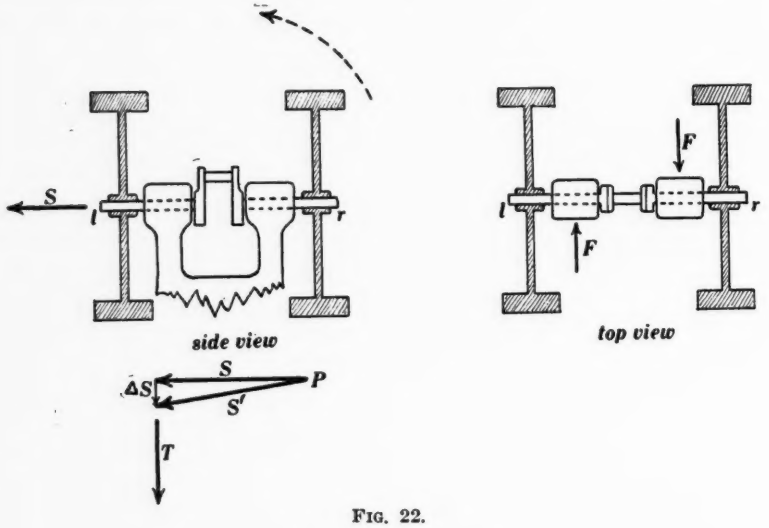


FIG. 22.

GYROSTATIC ACTION OF A ROLLING DISK

Fig. 23 represents a penny rolling along a floor. The forces *FF* in the side view (the tendency of the penny to fall over) constitute a torque which is represented by the arrow *T* in the top view. This torque produces during a short interval of time an increment of spin-

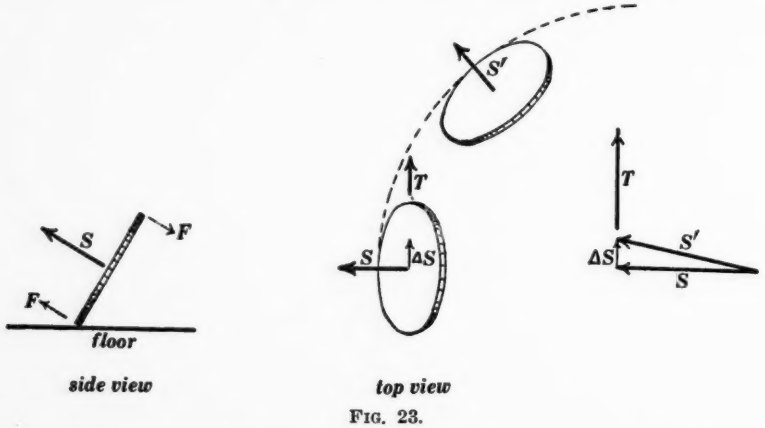


FIG. 23.

momentum ΔS which, added to the existing spin-momentum S, gives the resultant spin-momentum S' in the direction of which the axis of the penny is found to be turned. The result is that the penny rolls along a circular path as represented by the dotted curve in the top view, Fig. 23. The wheels of a bicycle exhibit a gyrostatic reaction when

the handle bar is turned, and although this gyrostatic action helps to maintain the equilibrium of the rider, it is very small in its effect as compared with the linear momentum of the rider and bicycle frame.

Fig. 24 is a top view of an axle and pair of drive wheels of a locomotive rounding a railway curve. The arrow S in the vector diagram represents the spin-momentum of the axle and drivers at a given instant, S' represents the spin-momentum at a later instant, ΔS represents the increment of spin-momentum, and T represents the torque which must act upon the axle because of its precession. To exert this torque the outer rail must push up with an excessive force against the outer driver, or, in other words, the outer driver must be forced downwards against the outer rail with more force than that which is due to the locomotive alone as it is rounding a curve. That is to say, the gyrostatic action of the drivers of a locomotive exaggerates the excess of pressure on the outer rail while the locomotive is rounding a curve.

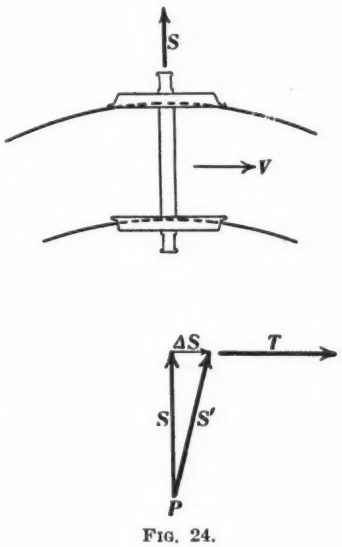


FIG. 24.

GYROSTATIC ACTION OF THE BOOMERANG

The most familiar type of boomerang is a pair of crossed sticks twisted very slightly at the ends like the vanes of a windmill. This type of boomerang, which we will call the propeller-wheel type, is essentially similar in its action to the boomerang of the native Australians. The boomerang is thrown through the air with a spinning motion about an axis at right angles to the plane of the crossed pair of sticks, and the peculiar flight of the boomerang is due to the forces exerted upon the boomerang by the air.

Forces are exerted upon the moving boomerang very much as if it were a disk traveling approximately edgewise through the air and forces are exerted upon the boomerang by virtue of its propeller-wheel shape and because of its combined spinning and edgewise motion. The effects of these two sets of forces will be described separately and their combined action will then be made use of in explaining the actual motion of the boomerang.

A disk moving approximately edgewise through the air is in an unstable condition, if the disk starts to glance to one side or the other the air exerts a turning force or torque upon it which tends to turn

it with its side flat against the air. This may be shown by dropping a thin paper disk through the air or by blowing a blast of air against a disk which is pivoted about a diameter as an axis. Fig. 25 repre-

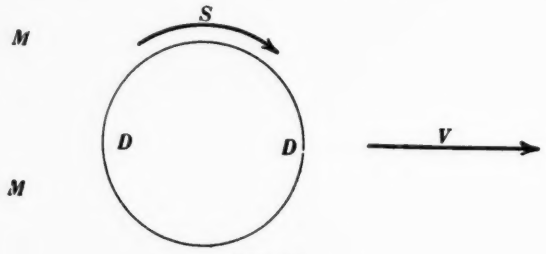
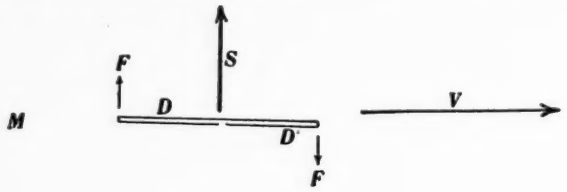


FIG. 25.

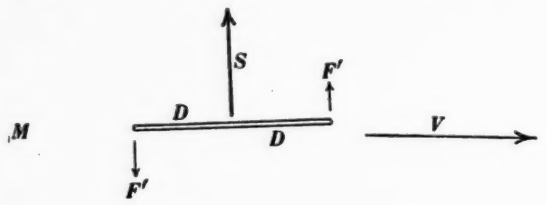
sents a thin metal disk *DD* which is thrown in the direction of the arrow *V* and at the same time set spinning in the direction of the curved arrow *S*, the thrower standing at *MM*. Figs. 26 and 27 are top views



top view

FIG. 26.

of the disk. Fig. 26 shows the disk starting to glance to the right (with reference to the thrower at *M*), and Fig. 27 shows the disk starting to glance to the left (with reference to the thrower at *M*). This glancing action of the disk causes the air to exert upon the



top view

FIG. 27.

disk a torque about a vertical axis in Figs. 26 and 27, which torque is represented by the forces *FF* in Fig. 26 and by the forces *F′F′* in Fig. 27. This torque would turn the disk flatwise against the air if the disk were not spinning, but the effect of the torque on the spinning

disk is to cause precession, the axis of spin of the disk in Figs. 26 and 27 turns towards the vertical, bringing the right-hand side (with reference to the thrower) of the disk in Fig. 26 upwards and bringing the left-hand side of the disk in Fig. 27 upwards.

Fig. 28 represents a propeller-wheel boomerang. In the following discussion the propeller is supposed to be right-handed, that is to say, if it were set spinning in the direction of the curved arrow S in Fig. 28, it would blow air towards the reader like a desk fan. Fig. 28 represents the boomerang as it leaves the hands of the thrower, who is supposed to be standing at MM, V being the direction in which the boomerang is thrown, and the curved arrow S representing the direction in which the boomerang is set spinning. The upper vane of the

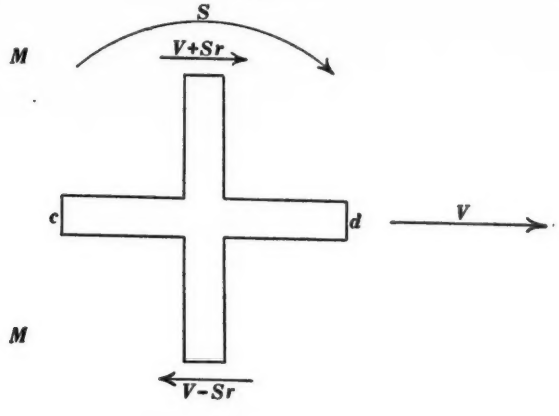


FIG. 28.

boomerang in Fig. 28 is traveling forwards at a greater velocity than the lower vane, because the forward velocity of the upper vane is the velocity of forward motion of the boomerang *plus* a forward velocity Sr which is due to the spinning motion of the boomerang, whereas the forward velocity of the lower vane is the forward velocity of the boomerang *minus* Sr. Fig. 29 is a top view of the boomerang as it leaves the hand of the thrower at M, V is the velocity of forward motion of the boomerang, and the arrow S represents the spin of the boomerang. The arrow F represents the force with which the air pushes sidewise against the upper vane because of propeller action. A force pushes sidewise in the same direction on the lower vane because of propeller action, but the sidewise force on the upper vane is the greater because of the greater velocity of the upper vane. The inequality of these forces constitutes a torque upon the boomerang, and this torque is represented by the arrow T in Fig. 29. The effect of

this torque during a short interval of time is to produce an increment of spin-momentum ΔS, and the addition of this increment of spin-momentum to the previously existing spin-momentum S gives a resultant spin-momentum S'. That is to say, the effect of the torque T is to cause the axis of spin to sweep around in the direction of the curved dotted arrow.

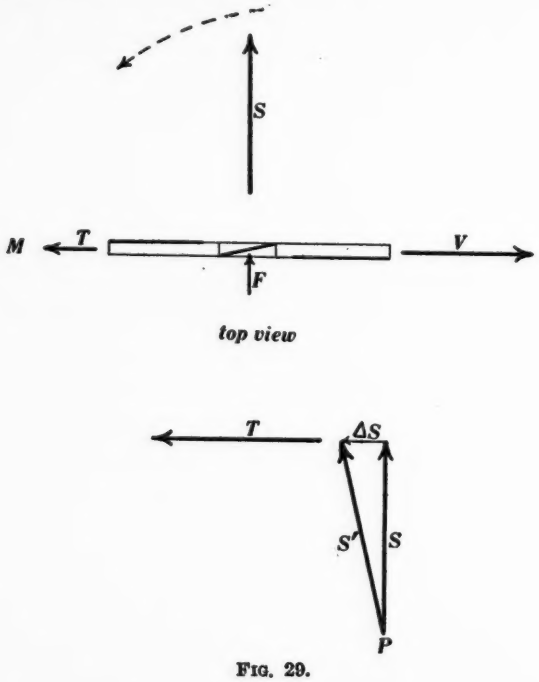


FIG. 29.

Fig. 30 shows a view as seen from above of an actual flight of the boomerang. The boomerang leaves the thrower at M with its plane approximately vertical, and the effect of the torque T of Fig. 29 is to cause the axis of spin of the boomerang to sweep about a vertical axis as represented by the curved dotted arrow in Fig. 29, thus tending to make the boomerang glance around a circular horizontal path. At the same time the boomerang acts more or less like a disk as represented in Figs. 25 and 27, and this action slowly brings the axis of spin of the boomerang into a vertical position (plane of boomerang horizontal). As the plane of the boomerang comes into an approximately horizontal position toward the end of its circular flight, the torque which is produced by propeller action (see Figs. 28 and 29) produces precessional motion which tends to raise the forward edge a and lower the backward edge b of the boomerang, thus causing the boomerang to tend to glance upwards. This tendency of the boomerang to glance upwards is helped by the propeller action of the boomerang, that is to say, the

boomerang, spinning in the direction of the arrows *SS*, Fig. 30, tends to climb upwards through the air. The result is that the curve of flight as shown in Fig. 30 is approximately a horizontal circle, the drooping of the curve of flight which would normally be produced by

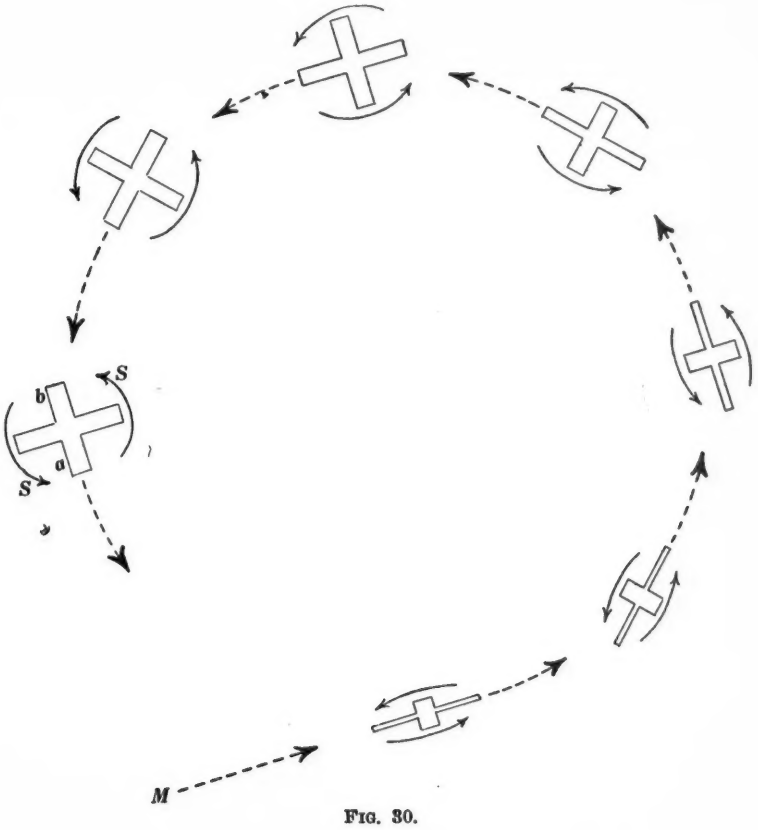


FIG. 30.

gravity being counteracted by the tendency of the boomerang to glance upwards and the tendency of the boomerang to climb upwards as specified.

THE DEVICE OF OTTO SCHLICK FOR THE PREVENTION OF ROLLING OF SHIPS AT SEA

Fig. 31 represents a spinning wheel hung upon a vertical axis from a hinge which permits the axis to swing to and fro in the plane of the keel of the ship (plane of paper in Fig. 31), the lower end of the axle being guided between two parallel bars. If the spin-momentum of the wheel were sufficiently great, all rolling motion of the ship could be eliminated, and the ship would heel over into a position for which the average heeling or rolling torque would be equal to zero; thus, the

spin-momentum produced by an unbalanced torque T' would be completely absorbed by the precessional motion of the spinning wheel as its axis of spin turns in the direction of the curved dotted arrow P', and the spin-momentum produced by an unbalanced torque T'' would

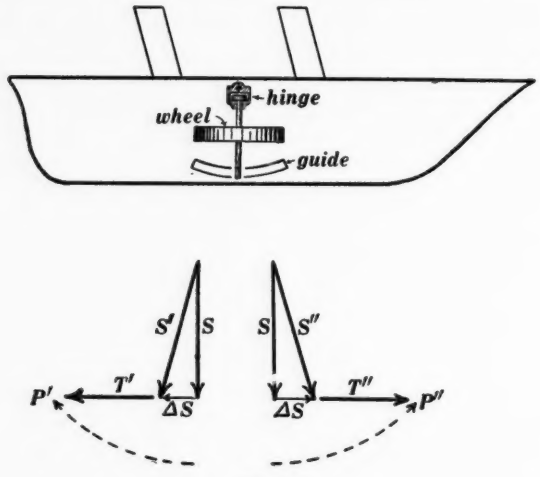


FIG. 31.

be completely absorbed by the precessional motion of the spinning wheel as its axis of spin turns in the direction of the curved dotted arrow P''.

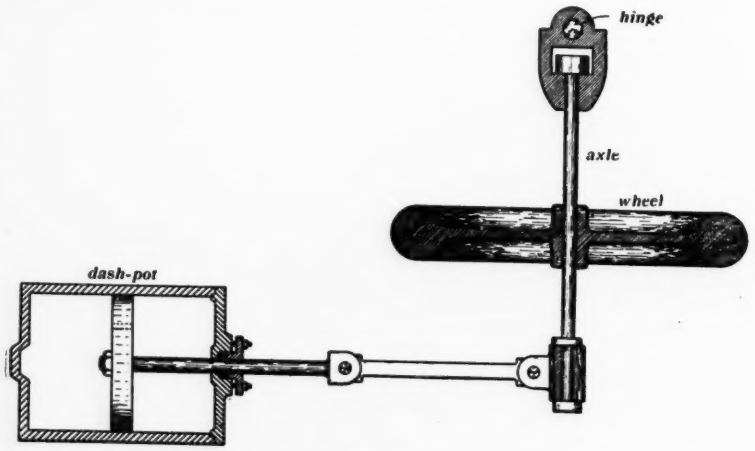


FIG. 32.

To completely hinder the rolling motion of a ship in this way would require the use of a very large wheel rotating at high speed. Thus a rolling torque (T' or T'' in Fig. 31) equivalent to 200 tons placed 10 feet to one side of the axis of the ship and continuing for only one tenth of a second would represent the whole amount of spin-momentum

contained in a solid steel disk 2 feet thick, 10 feet in diameter and rotating at a speed of 144 revolutions per minute; and therefore this amount of rolling torque continued for one tenth of a second would bring the axle of such a wheel into a horizontal position so that any further continuation of the torque would cause the ship to roll.

The rolling motion of a ship, however, is largely an oscillatory motion which is slowly built up by a succession of waves in synchronism with the proper period of rolling motion, and excessive rolling may therefore be prevented by an action which tends to hinder the oscillations by friction. A very considerable amount of frictional damping may be produced by a moderately small gyrostat arranged as shown in Fig. 32 (plane of paper in Fig. 32 is a vertical plane containing the keel of the ship). In this case the rolling motion of the ship causes the pendant wheel and axle to oscillate to and fro in the plane of the keel, and these oscillations are hindered by the motion of a piston in a dash-pot as indicated in the figure.

The Brennan Monorail Car

Before discussing the Brennan gyrostatic mechanism for maintaining the equilibrium of a monorail car, let us consider the action of the apparatus shown in Figs. 33 to 36, a gyrostat wheel mounted in a frame *aa* which in turn is pivoted in a larger frame *BB*, the whole

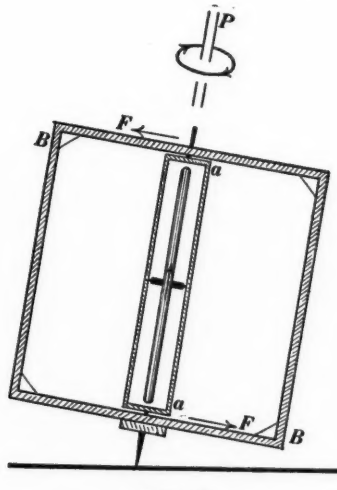


Fig. 33.

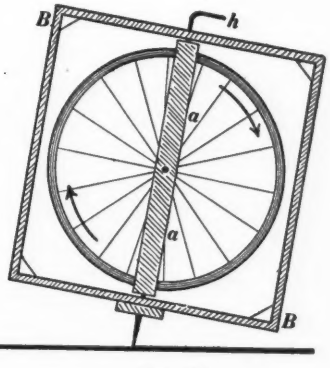


Fig. 34.

being supported upon two legs, one behind the other, as seen in the figures. Standing in the position shown in Fig. 33, the framework is acted upon by the unbalanced pull of the earth which produces a torque; the spin-momentum which is continually produced by this torque is absorbed by a precessional motion P of the gyrostat wheel as it

turns from the position shown in Fig. 33 to the position shown in Fig. 34, and the reaction of this precessional motion produces the two forces *FF*, Fig. 33, which keep the frame from falling over. When the gyrostat wheel reaches the position shown in Fig. 34, however, the precession ceases and the frame-structure falls over. Standing in the position shown in Fig. 35, the framework is acted upon by the unbalanced pull of the earth, which produces a torque, the spin-momentum which is continually produced by this torque is absorbed by the precessional motion *P'* of the gyrostat wheel as it turns from the position shown in Fig. 35 to the position shown in Fig. 36, and the reaction of this precessional motion produces the two forces *F'F'*, Fig. 35, which keep the frame from falling over. When the gyrostat

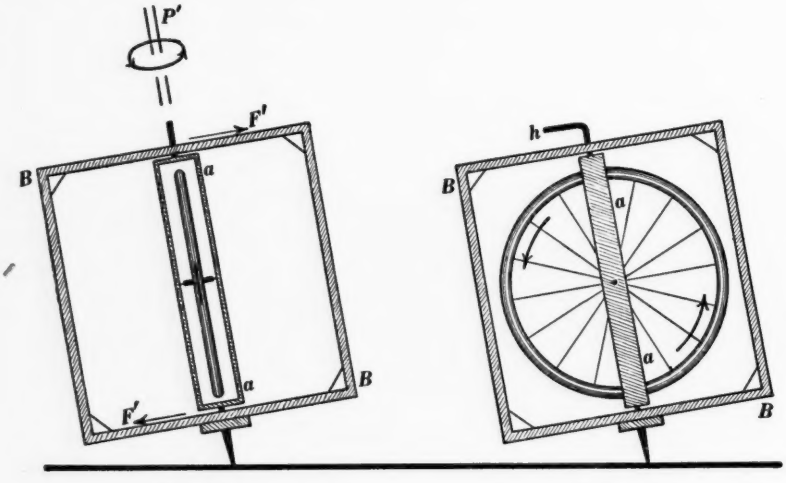


FIG. 35. FIG. 36.

wheel reaches the position shown in Fig. 36, however, the precession ceases and the frame-structure falls over. Suppose the handle *h* in Figs. 33 and 34 to be forcibly turned in the direction of the precessional motion *P*. This hastened precession causes the reactions *FF* to be more than enough to hold the inclined frame in position, and the result is to bring the frame into a vertical position, or, if the precession is hastened sufficiently, to throw the frame-structure over into the reverse position as shown in Fig. 35, thus starting the reversed precession *P'*. This hastened precession is the essential feature of the Brennan gyrostatic mechanism and it is brought about automatically as explained in the following discussion.

The essential features of the Brennan mechanism are shown in Fig. 37. The car body *BB'* supports a rocker-axle *O* which is parallel to the rail or rope *W* upon which the car stands. A steel frame *FFFF* is supported upon the rocker-axle *O*, and the two gyrostat wheels are

carried in two smaller frames *ff* and *f'f'* which are free to turn about the precession axles *P* and *P'*. The axles of spin of the gyrostat wheels are *ss* and *s's'*, and these axles project as shown at *A* and *A'*. The two gyrostat wheels spin in the direction of motion of the hands of a clock as seen from the outer ends of the axles of spin *A* and *A'*, respectively. The precession axles *P* and *P'* are geared together by sectors of gear wheels *G* and *G'*. The frame *FFFF* is hindered from turning about the rocker-axis *O* by the tables *H*, *L*, *H'* and *L'*; the tables *H* and *L'* extend backwards from the plane of the paper, and the tables *L* and *H'* extend forwards from the plane of the paper.

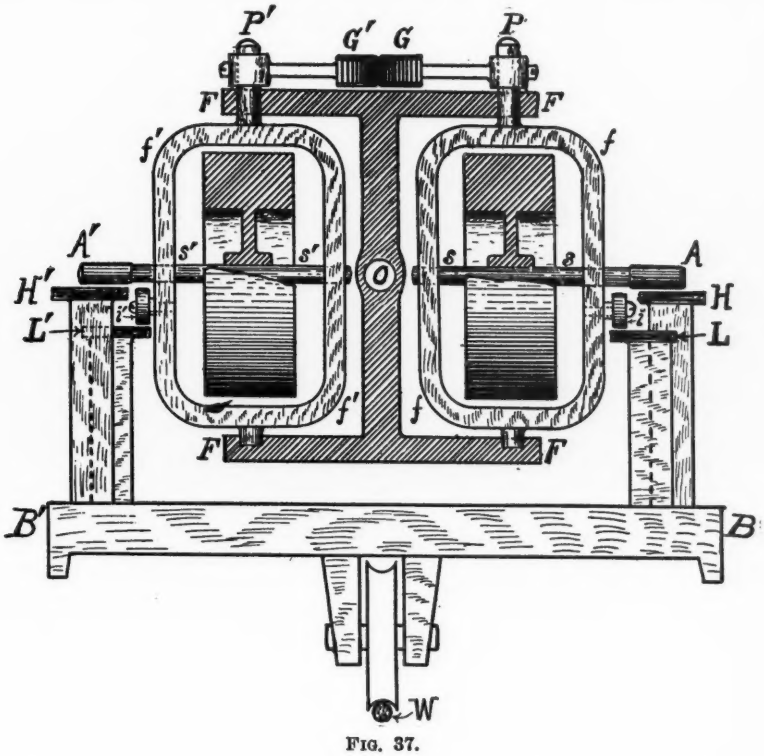


FIG. 37.

The action of this mechanism is as follows: Suppose side *B'* of the car body to be the heavier. The pull of gravity on this heavier side produces spin-momentum about the rail *W* as an axis, and this spin-momentum is absorbed by the precessional motion of the gyrostat wheels, causing both ends of the axles of spin *A* and *A'* to move away from the reader in the figure. The unbalanced car, however, in tending to tip over (side *B'* overloaded), brings the projecting axle *A* into contact with the table *H*, the rolling action of the axle *A* upon the table *H* hastens the precessional motion, and this hastened precession raises the side *B'* and lowers the side *B* of the car-frame, as explained

in connection with Figs. 33 to 36. This action continues until side B is heavier than side B', when the reversed unbalanced condition of the car body causes a reversed precessional movement of the gyrostat wheels. This reversed precession continues steadily and unhastened so long as the heavy side B is balanced by the contact of the idle wheel i' with the table L', that is, until the projecting ends of the axles of spin A and A' are brought forwards (in the figure) into the plane of the paper. Then the continuation of the reversed precession brings the axle A' upon the table H', the reversed precessional motion is then hastened, and this hastened precession raises the side B and lowers the side B' of the car-frame, thus bringing the car-frame into its initial unbalanced condition (side B' heavier than side B). The above-described action is then repeated, and so on.

The stability of the Brennan car is due to the hastened precession which is caused by rolling action of one or the other of the projecting axles of spin upon the tables H and H', while the axles of spin are *departing from* a line at right angles to the length of the car, and to the steady and unhastened precession, while the axles of spin are *moving towards* a line at right angles to the length of the car. The hastened precession on the one hand quickly alters the condition of balance of the car so as to limit the departure of the axles of spin from a line at right angles to the length of the car, and the steady and unhastened precession, on the other hand, insures the complete return of the axles of spin to a line at right angles to the length of the car.

The hastened precession is accomplished with great friction losses by the rolling axles A and A' in Fig. 37, and it is reported that Brennan is working upon an automatic motor-driven mechanism to produce the hastened precession without exhausting the energy of the gyrostat wheels.

Two devices like Fig. 37 with their rocker-axles at right angles to each other would hold a one-legged body in equilibrium; indeed, such a double mechanism would make it possible to use a one-wheeled car, but the wheel would have to have a deep double flange to make it roll along a rope or rail. Such a one-wheeled car, a sort of hyper-wheelbarrow car, would be of no value for practical use, and, indeed, most of us believe that Brennan's two-wheeled car is nothing more than a scientific toy.

Calculation of Torque-Reaction Due to Precession

Let n be the revolutions per second of a spinning wheel, P the revolutions per second (or the fraction of a revolution per second) of the axis of spin due to the precession, and K the moment of inertia of the spinning wheel in pound $\times$ feet squared. Then the torque reaction is equal to $4\pi^2nPK$ poundal-feet or $\frac{1}{3}\pi^2nPK$ pound-feet.[4]

[4] See Franklin and MacNutt's "Elements of Mechanics," p. 150.

JOSIAH WILLARD GIBBS AND HIS RELATION TO MODERN SCIENCE. III

By FIELDING H. GARRISON, M.D.

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Catalysis, Colloids and Chemical Purity.—When chemical change can be produced in a system by the mere presence of small quantities of another substance which itself usually remains unchanged at the end of the process, such an effect is called catalysis and the agent employed a catalytic agent. Of the varied aspects of catalytic processes we have different examples in the decomposition of substances by the presence of finely divided metals like platinum or colloidal nickel, in the rapid evolution of oxygen from potassium chlorate when a small quantity of manganese dioxide is present, in the solution of insoluble chromic chloride through the mere presence of chromous chloride, in the inversion of cane sugar by acids, in the saponification of fats and esters, in the synthesis of indigo by oxidation of naphthalin, in the standard manufacture of sulphuric acid in the leaden chambers and the later improvements of the method through the presence of platinum or ferrous oxide, in catatyptic photography without light, in the reversible physiologic and therapeutic action of the animal and vegetable ferments and enzymes, in the synthesis of nuclein during the development of the embryo, and in the pathologic effects of poisons, venoms and the toxins of disease. Many theories of catalytic action have been advanced, of which the earliest and most original is that of Leibig. Liebig supposes catalysis to be due to the fact that the catalytic agent has power, like that of a tuning fork, to set up sympathetic molecular vibrations in the substance acted upon, producing chemical change. This theory has been proscribed by Ostwald because, being a figment of the mind, it is neither capable of proof nor susceptible of refutation, leading the subject into a blind alley, from which further scientific advance is impossible.[101] It has therefore remained, like Hamlet's father, "quietly inurned," as a beautiful, imaginative hypothesis which we can neither prove nor disprove. Of other theories of catalysis the most important is that of Ostwald himself, summed up in his famous definition: A catalytic agent is one which modifies the velocity of a chemical reaction without appearing in its final process. This statement introduces two new ideas, the notion of infinite swiftness and infinite slowness in chemical change and the fact that catalytic change may be brought about by a series of intermediate reactions. It will be seen that Ostwald's definition is elastic enough to include as

[101] Ostwald, "Ueber Katalyse," Leipzig, 1902.

catalytic agencies such physical forces as light, electricity, extremes of heat or cold or the action of living tissues, and from this point of view the explosion of a cartridge or a charge of dynamite by percussion, the decomposition of water by electrolysis and its synthesis by the electric spark, the effects of light in photography and in healing disease, the wonderful thermodynamic effects of Henri Moissan's electric furnace, the occasional changes of food in cold storage, are further examples or analogues of catalytic action, and this is all we know of its physical nature. As to a dynamic explanation of how catalysis takes place, we have not got beyond the familiar jest of the laboratories: "*Q.* What is catalysis? *A.* Action by contact. *Q.* What is action by contact? *A.* Catalytic action." Gibbs's treatment of the subject is interesting as affording a mathematical criterion of what catalysis is and what it is not. It will be remembered that when the entropy of an isolated chemical system, say a bar of steel, has attained a maximum or its free energy a minimum value, the final state of the substance in question has been called by Gibbs a "phase of dissipated energy," implying that it has become physically and chemically inert, so that its equilibrium will not be sensibly disturbed by the presence of other substances or by such small physical agencies as an electric spark. But when the proportion of the proximate components of the substance in connection with its pressure and temperature is such that it does not constitute a phase of dissipated energy, the contact of a very small body or physical agency may produce energetic changes in its mass which do not stop short of complete dissipation. This is catalysis, and Gibbs's definition of a catalytic agent—one capable of reducing a substance to a phase of dissipated energy without limitation as to their relative proportions—is characteristic of the mathematician. A chemical system at constant temperature has several states of equilibrium corresponding to different minima of its isothermal potentials, and on the solid diagrams of Gibbs these minima are valleys at the bottoms of sloping curves. The effect of a catalytic agent on the diagram is to obliterate the ridge between two depressions representing different states of equilibrium on the free energy surface. This means that a system disturbed by a catalytic agent may pass from a higher to a lower minimum of free energy, but never from a lower to a higher unless acted upon by external forces of considerable magnitude. When the lowest minimum of free energy, indicated by the lowest depression on the diagram, has been attained, the substance can no more leave the final phase of dissipated energy than an inert body can be made to go up a hill without the intervention of external forces. On Gibbs's showing, the phase of dissipated energy is the criterion of catalytic action, the condition for which is that the substance acted upon should not have attained such a phase, while the forces operating flow, as in other mechanical, thermal, chemical or electric happenings, from higher to lower potentials. The accuracy of this reasoning is

borne out by Emil Fischer's researches in structural chemistry, which show that the intrinsic stability of chemical systems is usually such that it can not be disturbed by "intramolecular wobble," chemical change being brought about by extramolecular or catalytic influences. The mathematical treatment of catalysis gives us a deeper insight into phenomena which no one has as yet succeeded in explaining. "We have not," says Bancroft, "the first suggestion of an adequate theory of catalysis" so essential to a better understanding of chemistry and of life itself. A true theory of catalysis will enable us to solve the problem of the transmutation of the elements, of which we have already had examples in the substances derived from radium, and the recent derivation of tellurium from copper by Sir William Ramsay. The action of animal and vegetable protoplasm is probably catalytic and the chemist can now make some vegetable substances, such as indigo or alizarine, more cheaply and purely than the plants themselves do. Could we substitute inorganic catalyzers for the vegetable enzymes and ferments in all cases, we might, as Bancroft points out, duplicate everything except the plant itself. Recently Loeb has interpreted the fact that some eggs can be developed by osmotic pressure alone, while others require fertilization, by the explanation that, in the former class the nuclein synthesis, which is necessary for segmentation, is started within the nucleus as a catalytic process, one of the products of the reaction being the catalyzer itself; while eggs requiring fertilization are such that the necessary nuclein synthesis must be started by some external catalytic agency.[102] Again catalysis is the key to the causes and treatment of infectious diseases, the toxins and antitoxins of which are probably colloidal catalytic agents. A few drops of such a colloid as cobra venom will rapidly reduce a living animal body to a definite phase of dissipated energy, as far as its vital activity (or "free energy") is concerned, and such catalysts as colloidal metals, which Bredig has shown to act exactly like the ferments and enzymes, can themselves be "poisoned" or rendered inert by other substances, just as toxins, venoms and poisons can be neutralized by antitoxins or other antidotes. Gibbs did not discuss colloids explicitly, because substances of such indefinite or irregular formation do not admit of mathematical treatment as such, but the physics of what we know of their intimate structure is implicit in his chapters on chemical conditions obtaining at surfaces of discontinuity. Colloids are semi-solid substances, and colloidal solutions are "pseudo-solutions," being suspensions of minute, discrete particles of matter which are not true solutions, in that they obstruct the passage of light, while neither the freezing point nor the vapor tension of the solvent can be sensibly lowered. Graham thought of colloids as dynamic phases of matter, possessing internal energy, while crystalloids are static and inert. The former include reversible colloids like gelatine which, heated with warm water, will upon cooling solidify

[102] Loeb, *Science*, 1907, N. S., XXVI., 425–37.

into a "gel," and redissolve upon heating into a colloidal solution or "sol"; and irreversible colloids, which, when heated with warm water, will coagulate at once into an unchangeable precipitate. Living protoplasm, as Darwin has shown in his experiments upon Drosera and other plants,[103] acts exactly like a reversible colloid. Dead protoplasm, such as a coagulated blood clot, is an irreversible colloid consisting of a fixed network, the meshes of which contain the "sol." There is no evidence of internal structure in living protoplasm, and Hardy supposes that structure in dead protoplasm is produced by submortem or post-mortem changes associated with coagulation. Whether the phase rule can be applied to colloids is still an open question bound up with the complex nature of bodies of which we know so little. But recently Siedentopf and Zsigismony have shown that colloidal metals, organic ferments and enzymes are systems in two phases of vast surface tension consisting of suspensions of ultra-microscopic particles acted upon by chemical, thermodynamic and electric potentials. Of such suspensions animal and vegetable bodies are largely made up, protoplasm being a sort of microscopic emulsion, the physiological action of which seems to be bound up with chemical, thermal, electric and osmotic changes between its semi-permeable membranes and surfaces of discontinuity and the various surface tensions and surface energies derived from the free energy of chemical or electric change. If we conceive of colloidal solutions as made up in this way, each tiniest particle being an ultra-microscopic furnace, retort or battery in itself and carrying a definite charge of electricity, we can understand how Liebig's theory of sympathetic vibrations might be applicable to colloidal catalysis at least, and how finely divided metals, serpent venoms or the excretions of micro-organisms can produce the extraordinary effects they do. In close connection with the theory of catalysis is the nature of chemical purity and the fact that chemical changes rarely proceed directly to their final product, but usually pass through a series of intermediate stages. For a long time chemists have noticed that absolutely dry or pure substances will not interact directly upon each other, but the cooperation of a third substance is necessary for chemical change. Dried chlorine does not of itself act upon copper and other metals, but the presence of a little moisture will cause it to act upon them at once. A mixture of carbonic acid and oxygen is not explosive when thoroughly dry, but the slightest trace of steam will cause an explosion. The rapid solubility of zinc in sulphuric acid depends upon impurities in the former. Ebullition depends largely upon gaseous impurities in the boiling substance. Absolutely pure or distilled water has no digestive value, but, by its absorptive power, acts as an irritant or poison to the lining membrane of the stomach. Traces of moisture or other impurities have therefore a marked catalytic effect, a theory of catalysis which was first advanced as early as 1794 by Mrs. Fulhame in her "Essay

[103] Darwin, "The Power of Motion in Plants," *passim*.

on Combustion." Where water is the impurity, thermodynamic change is supposed to be due to electrolysis: the moisture being the necessary third ingredient for producing a little Voltaic circuit and the electric shock precipitating chemical action as in catalysis. The phase rule, Bancroft reminds us, has taught us to look upon an absolutely pure substance, 100 per cent. strong, as the extreme case of a two-component system, in which the concentration of the second component approaches zero as its limit. Gibbs has shown that in a system of two phases, one component of which is very small, the chemical potential of the dilute component is proportional to the logarithm of its density. As the density of the smaller component becomes less and less, its potential tends to an infinite value,[104] which means that, at the limit, when concentration becomes evanescent, "the removal of the last traces of any impurity would demand infinite expenditure of available energy."[105] From the view-point of mathematical chemistry there are many chemical substances that are relatively and approximately pure, but absolute purity of a chemical nature is, in Whetham's dictum, "more often a pious dream than an accomplished fact."[106]

Ideal Gases and Gas-Mixtures.—It is in the physics of gases that the application of the molecular theory has proved most successful and the laws and equations relating to gaseous states are of considerable accuracy owing to the fact that practically all gases act alike. Although Gibbs made no explicit assumptions as to molecular dynamics, his treatment of gaseous states agrees so well with the kinetic theory that Boltzmann thought he must have had the latter constantly before his mind in framing his fundamental equations.[107] These equations are unique in that Gibbs subjected them to an unusual test of accuracy by comparing their calculated densities of gas mixtures with convertible components with the actual measurements for nitrogen peroxide, acetic and formic acids and phosphorus perchloride[108] by Sainte-Claire-Deville, Horstmann and others. In the case of nitrogen peroxide the difference between the observed and calculated densities scarcely exceeded .01 on the average and was not greater than .03 in any case.[109] The agreement between the theoretical and actual values was equally striking for the other gases, and these results are among the most accurate and satisfactory in the history of physical chemistry. Interesting features of this section of Gibbs's work are his interpretation of

[104] *Tr. Connect. Acad.*, III., 194–7.

[105] Larmor, "Encycl. Britan.," 10th ed., XXVIII., 169.

[106] Whetham, "The Recent Developments of Physical Science," Philadelphia, 1904.

[107] Aus vielen Stellen geht deutlich hervor, dass Gibbs auch diese molekulartheoretische Anschauung fortwährend vor Augen hatte, wenn er auch von den Gleichungen der Molekularmechanik keinen Gebrauch machte." Boltzmann, "Vorles. über Gastheorie," Leipzig, 1898, II., 211.

[108] Gibbs, *Am. J. Sc.*, 1879, 3. s., XVII., 277, 371.

[109] *Tr. Connect. Acad.*, II., 240.

Dalton's law as implying that "every gas is as a vacuum to every other gas,"[110] his anticipation of van't Hoff's equation in the form of Henry's law for dilute solutions of gases in liquids[111] and his genial discussion of gas-mixtures, known in Germany as,

The Paradox of Gibbs.[112]—If two different gases which can be separated reversibly by quicklime or other process are allowed to mix, a certain definite amount of work or available energy will be gained; but if two gases, which are in every respect identical, are allowed to mix, they could not be separated by any reversible process and there would consequently be no gain of available energy in their mixing nor any dissipation of energy (increase of entropy). But if we suppose two gases which differ only infinitesimally to mix, the first condition would still obtain and there would still be a certain gain of available energy. The question arises, what will happen if we proceed to the limit? Maxwell explained this paradox by saying that our ideas of dissipation of energy depend upon the extent of our knowledge of the subject. Could we invoke Maxwell's demon and borrow his gift of molecular vision, we should perceive that when two identical gases mix there is in reality a complete dissipation of energy, which the demon's intelligence might turn into available energy if he liked; for "it is only to a being in the intermediate stage who can lay hold of some forms of energy, while others elude his grasp, that energy appears to be passing inevitably from the available to the dissipated state."[113] In the reasoning of energetics, the paradox is explained by saying[114] that the more nearly alike the gases are, the slower will be the process of diffusion, so that work or available energy might indeed be gained, but only after the lapse of indefinite or infinite time, if we have such time at our disposal.

Theory of Capillarity, Liquid Films and Interfacial Phenomena.—There are two important theories of capillary action, that of Laplace, based upon the assumption that the play of molecular forces in a liquid is only possible at insensible or ultra-micrometric distances, and that of Gauss, based upon the doctrine of energy. Gibbs's exhaustive discussion of capillarity, which takes up at least one third of his memoir, is the thermodynamic or chemical completion of the purely dynamic theory of Gauss. A capillary film or interfacial layer forms a new "phase" between the two substances on either side of it, and the mathematical condition for the formation of a new chemical substance at such an interface or "surface of discontinuity" is expressible as an algebraic relation between the surface tensions of the three layers of substance and the pressure of the three phases,[115] the surface tensions

[110] *Ibid.*, 218.
[111] Ibid., 194–7, 225–7.
[112] *Ibid.*, 227–9.
[113] Maxwell, "Encycl. Britan.," 9th ed., VII., 220, *sub voce* "Diffusion."
[114] Larmor, "Encycl. Britan.," 10th ed., XXVIII., 171.
[115] *Tr. Connect. Acad.*, III., 391–416.

being functions of the temperature and the chemical potentials. The only stable substance which can be formed between two other phases will be the one having the least surface tension.[116] The chemical equilibrium of solids in contact with liquids, including the delicate mathematical conditions for the formation of crystals in mother liquor, is treated dynamically as a matter of stresses and strains, and this together with the theory of interfacial formations and liquid films will embrace the possible physics of colloid substances. Gibbs gives for the first time a mathematical discussion of the mode of formation of liquid films and the conditions for their stability and his dynamic explanation of the black spots on soap films[117] was proved quantitatively in 1887 by Reinold and Rücker's micrometric data of the relations between the thickness and surface tension of these films.[118] The importance of liquid films in biology is obvious, and this phase of Gibbs's theory, which is capable of the widest development, has as yet received the slightest attention.

Electrochemical Thermodynamics.—One of the most important features of energetics is Gibbs's theory of the galvanic cell which shows the close interrelation existing between chemical, thermal and electric energy. The earliest pioneer in this field was Lord Kelvin, and, prior to 1878, physicists had accepted the Joule-Kelvin theory that the electromotive force of a galvanic apparatus is the mechanical equivalent of the total chemical energy liberated per unit strength in unit time. But this view, which implies that all the electric energy of a chemical cell is available, did not agree entirely with the experimental data of Boscha, Raoult and others. It was corrected and modified by Gibbs, who showed that the electromotive force of the cell is in reality its free energy per electrochemical equivalent of decomposition,[119] from which it follows that neither solidification nor fusion of the metals at the temperature of liquefaction should cause any abrupt alteration of the electromotive force. In 1882, six years later, this important theorem was rediscovered from a different view-point by Helmholtz and brilliantly developed as to experimental confirmation.[120] The Gibbs Helmholtz doctrine enables the physicist to trace out the variations in electromotive force due to chemical differences in different cells. In a letter to Professor Bancroft, now printed in the memorial edition, Gibbs connects the mathematical part of his theory of the electric cell with the fundamental principles of physical chemistry, the theories of van't Hoff and Arrhenius, Nernst's osmotic theory of the Voltaic cell

[116] *Ibid.*, 403.

[117] *Ibid.*, 479–81.

[118] *Phil. Tr.*, 1887, CLXXVII., 627, 684.

[119] "The quantities of the different substances combined in connection with the passage of a unit electricity are called the electrochemical equivalents of these substances." Bryan, "Thermodynamics," 164.

[120] Helmholtz, *Sitzungsb. d. Berl. Akad.*, 1882, 22 et seq.

and the equations of Ostwald and van der Waals.[121] But perhaps his most important contributions to the theory of electricity are the two papers on electrochemical thermodynamics which he sent to the British Association in 1886 and 1888; Helmholtz, in his well-known formula for electromotive force, gives a relation such that if a cell be set up, and the reversible heat measured, the electromotive force need not be measured, but may be calculated from these data, or *vice versa.* In Gibbs's *rendement* of the perfect (or reversible) galvanic cell, both the electromotive force and the reversible heat can be predicted from his equation without the necessity of setting up any cell at all. "Production of reversible heat," says Gibbs, "is not anything incidental, superposed or separable, but belongs to the very essence of the operation."[122] In discussing the matter in 1887, Sir Oliver Lodge raised the question whether Professor Gibbs was not regarding a galvanic cell as "too simply a heat engine" or assuming that the union of the elements in a cell primarily produces heat and secondarily propels a current.[123] Gibbs replied that "in supposing such a case we do not exceed the liberty usually allowed in theoretical discussions" and proceeded to show, in an ingenious demonstration, that Helmholtz's equation flows as a natural consequence from his own earlier results.[124] The accuracy of his reasoning is sustained by such developments of the subject as the "Peltier effect," in which it is demonstrated that the thermoelectric effect in systems of conductors, in which no chemical action takes place, is still proportional to the absolute temperature at any junction. In general the properties of a thermoelectric system are determined by the entropy function, and the entropy and energy in a thermoelectric network are not, as previously supposed, stored in the conductors, but, as we see in the electric transmission of motor power from a waterfall like Niagara to an engine or railway car, actually travel with the moving charge of electricity itself. In short, "entropy can be located in an electric charge."[125]

Such are a few of the mathematical and physical consequences flowing from the single idea of entropy, and they are sufficient to define the position of Gibbs in the history of thermodynamics. In the establishment of the dynamical theory of heat, says Larmor, "The name of Carnot has a place by itself; in the completion of its earlier physical stage the names of Joule and Clausius and Kelvin stand out by common consent; it is, perhaps, not too much to say that, by the final adaptation of its ideas to all reversible natural operations, the name of Gibbs takes a place alongside theirs."[126]

[121] See Bancroft, *J. Phys. Chem.*, 1903, VII., 416–427.,

[122] "Report British Association for the Advancement of Science," 1886, 388.

[123] *Loc. cit.*

[124] "Report British Association for the Advancement of Science," 1888, 343–6.

[125] See Bryan, "Thermodynamics," Leipzig, 1907, 174, 198.

[126] *Proc. Roy. Soc. Lond.*, 1905, LXXV., 292.

(To be continued)

A REVOLUTION IN DENTISTRY

By RICHARD COLE NEWTON, M.D.

HAVE the dentists waked up? Some of them have. A new order of the "Knights of the Forceps" has been formed, called the "Orthodontists" (tooth straighteners). At last accounts there were sixty of them in America, as compared to 50,000 simple dentists. And what does it all mean? If I can compress a great deal of information into a limited space I can, perhaps, explain it and I think that it may be possible to make it clear why the movement is so important.

Dr. Osler has said that the question of preserving the teeth is more important than the liquor question. When one reflects that a great deal of intemperance is caused by dyspepsia, with its mental and physical deterioration, and that the underlying cause of much of the generally prevalent dyspepsia is the decayed and defective teeth, which preclude complete mastication of the food (even if anybody in America had the time to eat properly), the solid truth of Dr. Osler's remark begins to dawn upon us.

Now the dentists, like the doctors, have begun to realize that their true mission is not "a general repairing business," but a systematic and well-considered effort to prevent and forestall the wholesale decay and loss of human teeth. Perhaps some idea of the very general use of false teeth may be gathered from the statement that 20,000,000 of them are exported from America to England every year. When we consider that probably not more than half of the inhabitants of that country indulge in the luxury of false teeth, no matter how many "grinders" they may have lost, these figures would seem to indicate that nearly every one in England suffers from defective or missing teeth. Observations so far as they have been carried in the United States show the same deplorable state of affairs.

A great many more or less ingenious explanations have been advanced from time to time, to account for this, as well as for the fact that so few Americans have regularly disposed teeth and well-shaped jaws. Our English friends have made much sport of our "hatchet faces," "lantern jaws" and the nasal tones of our voices. We are told that such an admixture of races, as is gradually taking place in our country, is the cause of our poor teeth. Nobody seems to know why it should be so. In fact, such a result is directly opposite to nature's beneficent course in admixtures of different races and species, where

the tendency is to preserve the best and strongest features and eliminate the weak and faulty ones. I remember an elaborate article in some magazine, some years ago, which explained the great prevalence of poor teeth in America by saying, that they are caused by our habit of shaving our faces, while the orientals have sore and weak eyes because they shave their heads. The filth in which the latter live was not taken into account, nor the fact that the American women, who do not shave, have as bad teeth as the men.

A rather ingenious explanation of the marked disproportion between the size of the teeth and that of the jaw in many Americans, as for example, large teeth in small jaws, so that the former are crowded out of position and overlap one another, is that the big teeth are inherited from one parent and the small jaws from the other. This sounds plausible and since no systematic effort has, so far as I know, been made to find out the truth of the matter, it has been tentatively accepted for want of a better explanation of an exceedingly common phenomenon.

Recently some good observers, notably Dr. Sim Wallace and Dr. Harry Campbell, of England, have said that the trouble is not hereditary at all, but begins in each person's babyhood, and that our teeth are poor and irregular and our jaws contracted because we do not exercise these parts sufficiently from infancy to manhood; especially from weaning until six years of age, when the permanent teeth begin to erupt. In support of this statement they point out that the first set of teeth is practically never irregular, never overlaps and is very seldom defective. The beautiful lines of a baby's face are not distorted by irregular or protruding teeth, nor sunken by reason of the non-support of sufficiently wide jaws. The teeth of savages, Hottentots and Esquimaux are almost invariably excellent, and their jaws and tongues are wider and stronger than ours. This has been proved by the measurement of thousands of skulls as well as by observations upon the living inhabitants of the tropics and the arctic regions.

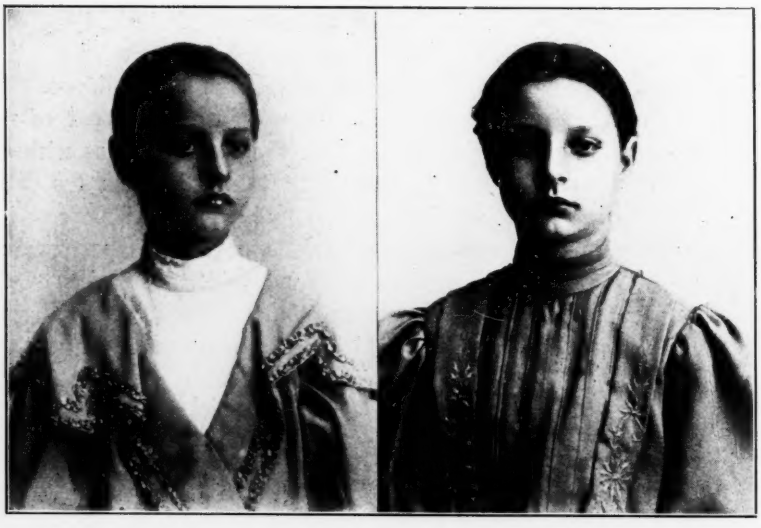
Dr. Campbell also points out that the frequent occurrence of adenoids in young children is caused by feeding them chiefly "pap." He calls this the "pap age." The good old-fashioned plan of chewing sufficiently hard and dry food to properly exercise and develop the jaws and teeth, seems to have been abandoned in our effete civilization. Instead of the honest "johnny cake" (called in the south "corn pone" or "hoe cake") upon which such sturdy characters as Andrew Jackson and Abraham Lincoln were wont to subsist—and, by the way, the American negro had good teeth and practically escaped tuberculosis so long as he lived upon simple corn bread and bacon and the vegetables and fruits from the plantation. I started to say, however, instead of corn bread and Boston brown bread and rye and "injun" bread, the breads of our grandfathers, which required mastication and insalivation

before they could be swallowed, our children now are fed on "previously cooked" breakfast foods, infant foods and other starchy viands, which may differ in name and flavor; but agree in two characteristics, viz., that they pander to lazy housekeeping, by requiring very little preparation for the table, and, secondly, require little or no mastication, before swallowing. Wetted with milk or cream they "slip down" very easily, and are landed in a stomach not prepared for a deluge of unchewed and non-insalivated starchy food. Hence the common cry of "starch indigestion." This is not wonderful because the proper digestion of starchy food must begin in the mouth, and is impossible without complete mastication. We are told in *Science* that in feeding meal to calves, "it must be spread thinly upon the bottom of the troughs so that it will be eaten slowly and insalivated." This is only one instance out of many where man's commercial instinct has taught him an invaluable truth in regard to the rearing of stock, that has a market value, but which it never seems to have occurred to him is just as important in connection with the rearing of his own children.

So far as the improper development or non-development of our teeth, jaws, tongues and lips is concerned, the trouble begins with the nursing bottle from which the infant gets its nourishment too easily and too rapidly, so that these important structures are all more or less undeveloped, and this non-development is a continuous performance up to adult life. Of course removal of adenoids, regulation of the teeth, boring out the nasal cavities and so on, are resorted to with great benefit, to obviate defects that should have been prevented by mothers nursing their babies and then making the children chew their food as nature intended them to do. If a child will not chew its food, the despised habit of chewing gum, now known to have prevailed among the Indians, should be encouraged.

Dr. Robinson, an English writer, calls attention to the development of the jaws of English boys who were taken out of the streets of London and sent into the British navy. He says "undoubtedly the most noticeable improvement in them, next to their superior stature and healthy appearance, was the total change in the shape and expression of their faces. On analyzing this, one found that it was to be mainly accounted for by the increased growth and improved angle of the lower jaw." This change was due to the rations of "hard tack" and "salt junk" upon which these lads had subsisted. A very satisfactory diet from an orthodontological point of view at least. It is plain enough that ninety per cent. of dental work might have been avoided; just as ninety per cent. of the sickness and premature death in the world is needless and could be prevented. The dentists have made the astonishing discovery that they can alter and enlarge the jaws of any child by simple means and they have found out, moreover, that the teeth

themselves and their arrangement are the pattern from which the jaw takes its shape. The teeth in different skulls differ so much, that it is extremely difficult, if not impossible, to "match" a missing tooth in one jaw with a tooth from any other one. The natural teeth then have an individuality in keeping with each particular face, and when they are in good condition and in their proper position, can not but add to the beauty, dignity and symmetry of the face. Three people out of four seem to lack in the proper development of the lower part of the face by reason of defective and misplaced teeth, and weak and ill-developed jaws. Hence we see that the "man of destiny," "the man with firm jaw, who knows his own mind," is presumably one who was made to chew properly in childhood, and was not allowed to wash down his food half chewed, or unchewed by gulps of liquid.



Before. After.

It is not true, that the teeth must fit into the jaws; the reverse is true, the jaws form themselves around the teeth. The bone grows around the roots of the teeth and forms a socket like the mortar or cement around the bricks in a fire-place. This is easily demonstrated; a tooth, for example, can be completely turned round or moved from one place to another, and, as we say, it grows "fast." For that matter, teeth, as is well known, can be extracted, cleaned and put back again, or teeth from one person's mouth can be put into the place of an extracted tooth in another's mouth and become firmly imbedded and do good service for years. The part of the jaw-bone that embraces the roots of the teeth is called the alveolar process, and it continues to grow and harden for some time after the teeth have been erupted, or after

they have changed their places in the jaw. Upon this elemental truth is founded the art of orthodontia. Were the facts not as stated, it would do no good to alter the positions of teeth, since they would not retain their new positions after they had been moved into them. The fact that the jaws can be widened by spreading the teeth, taken in conjunction with the adaptibility of the "alveolar" process, make the remarkable results of the orthodontist possible. The size, shape and strength of the lower jaw, or mandible, depend in great part upon the work it has to do, and furthermore, the shape of the upper jaw is determined by that of the lower. The lower permanent teeth are erupted first, and by their repeated impactions upon their opponents in the upper jaw, aided by the constant restraining and forming action of the tongue and lips gradually force the upper teeth into their proper

After. **Before.**

places and keep them there. Provided, that the lower jaw and the tongue and lips are strong and well developed, made so by sufficient chewing, especially from the years of two to six, in a child's life. If the child's education in chewing, however, has been neglected, the dentist can and does spread the jaw as already stated, so that it will have room enough for all the teeth. In other words, orthodontia does what nature would accomplish unaided were her simple laws of development properly observed.

A full set of teeth forms a beautiful arch, no stone of which should be missing. The shape and span of this arch are greatly determined by the size and position of the four permanent first molars, "six-year-old molars," the largest and most important teeth in the head. If these teeth are properly disposed in the jaws, the regulation of the

remaining teeth is much easier than otherwise. If they are out of place, they must be brought back to where they belong, because it is essential that they should be in their proper position and serve as the guides for the regulation of all the other teeth. Then by measuring the width of one of the eye teeth and the two front teeth next to it, a diagram can be drawn which will show the exact shape and size which the jaw should have. A very simple arrangement of springs and wires, which need hardly annoy the child at all, will soon spread the jaws and give the teeth room, so that those that are out of alignment can be brought into their proper places in the arch.

In this arch, like the arch of a bridge over a stream, every tooth must bear its proper share of the pressure, and its loss can never be replaced. A moment's reflection will show the folly of extracting teeth to make room for those out of alignment, and modern dentistry has

Before. After.

proved that such extraction will defeat the object for which it is undertaken, viz., the restoration of the perfect denture. A man who will extract a tooth in regulating may be foolishly clinging to the old tradition, that was spoken of just now, that the unfortunate child had inherited large teeth from one parent, and small jaws from the other. I remember, by the way, in my own boyhood, I seriously thought that I had by mistake got somebody else's teeth, because my permanent teeth were so large and broad, that my jaws could not accommodate them, and were so crowded that several were extracted to make more room. Now I know that my "hatchet face" and "lean jaws" might easily have been prevented had some modern orthodontist, who would die before he would extract a sound tooth, given me the proper advice and care.

A little patient of my own (see photograph) was told by her dentist that her upper front teeth would have to be extracted, as they protruded so that she could not close her mouth. On hearing this, I was simply horrified. I induced the parents to consult a competent orthodontist, with the result that on meeting the child on the street about three months afterwards (see photograph), I didn't recognize her. Here are two pictures of a dentist's son "before and after taking" a course of treatment. His father regulated his teeth.

In orthodontia an inconceivably great advance has been made in preserving human beauty, health and efficiency. And the people who have been bewailing nature's inadequacy and asserting that our race is gradually deteriorating so that the coming man will be "edentulous" (toothless) are asked to take a back seat. They belong in the same category with the people in Philadelphia, who objected to opening some playgrounds to children, because the latter shouted when they played. Just as if play without shouting could be any good for young children; even in Philadelphia.

A great and beautiful truth has been taught us by these orthodontists. Every good man, every religious man, and every one who rejoices in beauty, in symmetry, in efficiency and in the comforting reflection that nature does not make mistakes—man makes the mistakes, and is sometimes blasphemous enough to lay the blame upon God—ought to rejoice at the clear proof that there was no mistake made in allotting thirty-two teeth to an adult human being. That the properly shaped jaw can hold all of these teeth, and that modern ideas of the fitness of things demand a full complement of teeth in a properly shaped jaw. That the firm well-rounded chin, the resolute jaw and symmetrical cheeks, and the appearance of decision, vigor and alertness so necessary for either male or female beauty of expression, belong by right to every American man and woman; not to mention the fact that the "laughing pearls" of perfect teeth can be possessed by any one, and some one has sinned, either the man or his parents, if the denture is defective and the jaws ill-developed.

THE ORIGIN OF THE NERVOUS SYSTEM AND ITS APPROPRIATION OF EFFECTORS

I. Independent Effectors[1]

By G. H. PARKER

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THE physiological unit in the operations of the nervous system is the reflex. Broadly understood, this consists of the chain of consequences that begins with the reception of a stimulus on the surface of the animal and, leading through the central nervous organs, ends in the excitation of a reaction by some such organ as a muscle. The term reflex is made to apply nowadays to nervous operations involving conscious states as well as to those that are carried out unconsciously. In its greatest simplicity the conventional reflex involves at least two nervous cells or neurones and some form of reacting organ

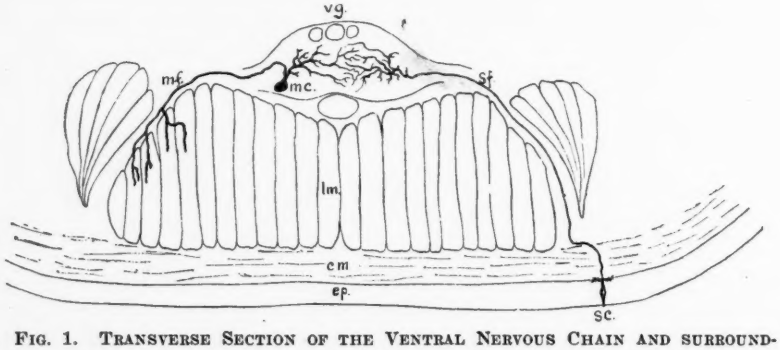

FIG. 1. TRANSVERSE SECTION OF THE VENTRAL NERVOUS CHAIN AND SURROUNDING STRUCTURES OF AN EARTHWORM (modified from Retzius). *cm*, circular muscle; *ep*, epidermis; *lm*, longitudinal muscle; *mc*, motor cell-body; *mf*, motor nerve-fiber; *sc*, sensory cell-body; *sf*, sensory nerve-fiber; *vg*, ventral ganglion.

such as a muscle-fiber. The first neurone, as exemplified in the nervous structure of such an animal as the earthworm, is often the body of a sense-cell on the surface of the animal and the sensory nerve-fiber to which this cell body gives rise and which leads to the central nervous organ. The second neurone is a nerve-cell whose body lies within the central nervous organ and whose process, a motor nerve-fiber, extends from the central organ to the muscle-cells which it con-

[1] The four articles in this series represent four lectures given at the University of Illinois between March 30 and April 3, 1909.

trols. The first neurone as it enters the central organ breaks up into a large number of delicate branches which are in physiological continuity with similar branches from the second neurone. It is over these delicate branches that the nerve-impulse passes from one neurone to the other and it is the structure of this system of branches that has been a matter of so much discussion within recent years. Anatomically, then, this simplest form of central nervous organ consists of motor cell-bodies and fibrillations from these bodies and from sensory neurones. Of course most central organs include additional neurones, such for instance as association neurones, which connect one part of the central organ with another and do not participate directly as sensory or motor constituents. The simplest conceivable reflex mechanism, however, does not include these, but only the sensory and the motor neurone as described. Such a chain reaching from the periphery of the animal through its central nervous organ to and including its muscles is usually regarded as the primary type of neuromuscular mechanism.

From a physiological standpoint this simplest type of reflex mechanism falls into three parts. The first of these is the sense organ or receptor, which, as its name implies, receives the external stimulus; the receptor is also the seat of the production of the nerve-impulse. The second is the central nervous organ or, as it may be called, the adjustor, which is concerned with directing the impulse toward the appropriate end-organ and with modifying it in accordance with the particular reaction to be obtained. The third and last is the effector or organ brought into action by the impulse, such as a muscle or gland. Thus a simple reflex may be said to involve at least three special classes of mechanisms: receptors, adjustors and effectors. These mechanisms, however, do not correspond exactly to the three histological elements already named, for, though the receptive function is an activity limited entirely to the first neurone in such an animal as the earthworm, and the effector is the muscle-fiber, the adjustor is a part of the first as well as of the second neurone and is made up of at least the fine fibrillar material contributed by these two neurones to the central nervous organ. The neuromuscular mechanism even in this its simplest type has probably not sprung into being fully formed, but it has had without doubt a slow and gradual growth. It is one of the objects of these articles to trace as far as possible the steps in this growth.

It is to be noted that every reflex mechanism is in the nature of a physiologically continuous span of living substance which reaches from the receptive surface on the one hand to the effector organ on the other. At no point in this span can there be a real interruption, for a physiologically continuous thread of protoplasm must connect the two extremes. It is, therefore, conceivable that a reflex mechanism might

exist in the body of a protozoan and in fact there is experimental evidence to show that in certain infusorians the superficial protoplasm is somewhat differentiated as a receptive surface and that this protoplasm also serves as a conducting organ whereby, for instance, the activity of certain groups of specialized cilia in these animals is coordinated. These conditions, however, are found within the substance of a single cell and are so remote from those of a true nervous mechanism that, interesting and significant as they are, they had better be termed neuroid than nervous. They show at best that the protoplasm of the protozoan harbors operations that may develop in the multicellular animals into reflex processes rather than that the protozoans possess these processes, and that we must look among the simplest metazoans for the beginnings of a true neuromuscular mechanism.

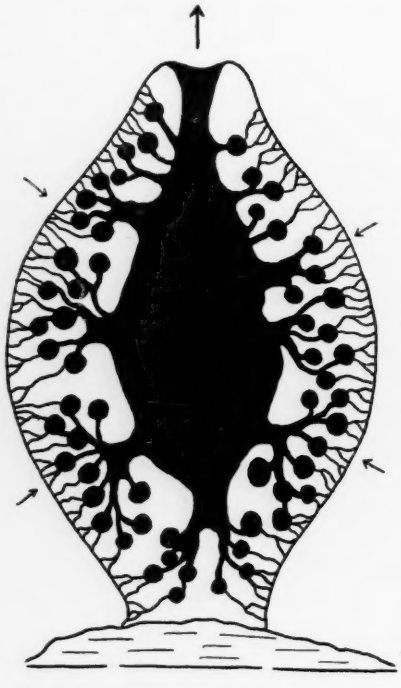

FIG. 2. DIAGRAM OF THE CANAL SYSTEM OF A CALCAREOUS SPONGE (modified from Haeckel). The lateral inlet pores receive water from the exterior, as shown by the arrows on the sides; the osculum at the apex discharges water to the exterior.

In making a quest for the first stages in the development of the nervous system, it is important to keep in mind the relative significance of the three physiological elements already pointed out: the receptors, the adjustors and the effectors. A little reflection will show that these three are not likely to prove all of primary significance.

A receptor or sense organ alone would be of no service whatever to an animal; it would resemble a telephone receiver disconnected from the rest of the system. In a similar way the adjustor or central organ is useless without at least some other element in the reflex apparatus. The only mechanism sufficient in itself is the effector, which, if it can be brought into action by direct stimulation, may accomplish something serviceable to the animal. It is therefore improbable that we shall find multicellular animals that possess either receptors or adjustors without effectors, but it is conceivable that primitive metazoans may have effectors without other parts of the typical neuromuscular mechanism.

In a search for the earliest traces of the neuromuscular mechanism,

we may turn first to those very primitive metazoans, the sponges. The body of one of the simpler sponges is a more or less goblet-shaped, multicellular mass, whose surface is covered with an enormous number of minute pores; these lead into tubes which in turn communicate with a relatively large central cavity that opens to the exterior by an aperture of considerable size, the osculum. In a living undisturbed sponge, water is continually passing into the lateral pores, through the tubes and central cavity, and out at the osculum. This current is produced by means of numerous cells, the choanocytes, which are provided with vibratile lashes and are variously distributed through the internal chambers and tubes of the sponge. Apparently these choanocytes work incessantly, and the current generated by them carries food, etc., to the sponge and removes waste products. Although frequent efforts have been made to show that nervous structures occur in sponges, nothing of this nature has been conclusively demonstrated and it is now generally believed that these animals are without differentiated nervous organs, either sensory or central. Nevertheless, sponges are capable of a certain amount of response. Merejkowsky (1878) observed that when he pricked with a needle the inner face of the osculum of *Rinalda,* this aperture quickly closed, not to open again for several minutes. The same reaction occurs with the lateral pores of many sponges (Vosmaer and Pekelharing, 1898). This power of closing the pores seems to be the only means by which a sponge may check the current which ordinarily flows through its canals, for, as already mentioned, the choanocytes apparently lash the water incessantly.

When a search is made for the organs concerned with the closing of the pores and oscula, they are found to consist of rings of elongated contractile cells or myocytes, which surround these apertures. These rings of cells form veritable sphincters and their action is often efficient enough to bring about a complete temporary closure of the aperture. Whether the pores and oscula open by the counteraction of radial, contractile myocytes or by the simple elasticity of the surrounding tissue does not seem to have been determined.

Since these sphincters lie very close to the epithelium that bounds the surfaces of the pores or oscula and in fact probably often form a part of this very epithelium, and since no nervous mechanism is known to be connected with them, it seems very probable that they are brought into action by direct stimulation and that the sponge is a metazoan in which there are functional effectors unassociated with receptors or adjustors. Thus the sponge would represent the first stage in the differentiation of a neuromuscular mechanism, *i. e.,* one in which the effector in the form of a primitive muscle-cell is the only element present. In my opinion it is around these contractile cells that the nervous organs of the higher metazoans have developed and I therefore

believe that these effector elements are the most primitive members in the typical neuromuscular mechanism.

That there is absolutely no trace of nervous activity in sponges is probably not true, but their extreme inertness shows that this function is certainly in a most primitive state and corresponds at best probably only to that sluggish form of reception and transmission that Kraft (1890) demonstrated for ciliated epithelium and that is probably characteristic of other epithelia. Taking all in all, the only element of the neuromuscular mechanism that is really present in sponges is the effector as represented by the sphincters of the pores and oscula.

If independent effectors occur in sponges, it is not unlikely that they may be present in the higher animals, and as possible examples of these the sphincter pupillae of the eye in vertebrates and the heart-muscle may be considered. The sphincter pupillæ is a ring of muscle imbedded in the iris and surrounding the pupil in the eyes of most vertebrates. Its contraction would naturally reduce the size of the pupil and thereby diminish the amount of light that enters the eye. In the higher vertebrates it is well known that this reaction has the character of a simple reflex in which the retina is the receptor, with the optic nerve as its transmitting organ, and the stem of the brain is the adjustor from which the oculomotor nerve transmits peripherally to the effector, the sphincter pupillæ. In the lower vertebrates, particularly in the fishes and amphibians, it has long been known that the sphincter pupillæ will react in a characteristic way even in extirpated eyes. This fact has been explained by those who cling to the idea of a reflex as due to intraocular nervous connections between the retina and the sphincter. But Steinach (1892) demonstrated the contraction of the pupil in the extirpated eyes of lower vertebrates from which the retina had been removed and moreover he showed that when a minute beam of light was thrown on a part of the sphincter, that part contracted first and was followed later by the rest of the muscle, an observation recently confirmed by Hertel (1907) in the eyes of higher vertebrates, including man. It therefore seems quite certain that the sphincter pupillæ of the vertebrate eye, though usually controlled by nerves, is a muscle that can be directly stimulated and in this respect is an independent effector like the sphincters of the pores in sponges.

A second case of independent muscle action in the higher metazoans is the heart-muscle. This muscle for a long time past has been the occasion of much discussion. In the vertebrates it is still an open question whether the beat of the heart is primarily nervous or muscular in its origin and the neurogenic and the myogenic theories of heart action have had a lengthy history (Engelmann, 1904; Howell, 1906). To Harvey we owe not only the discovery of the circulation of the blood, but the first true ideas of the action of the heart, for he showed that

the active phase of the heart-beat was during contraction, not during expansion, as had been generally supposed, and that the heart was in reality a muscular force pump. Harvey seems likewise to have had the idea, though perhaps not very clearly expressed, that the heart-beat was dependent upon the heart-muscle and not upon some extra-cardiac mechanism. In this sense he may be regarded as the founder of the myogenic theory. Later Willis pointed out that the stomach, intestine, and heart received nerves from the brain and he believed that the movements of these parts were controlled by such nerves; he therefore may be looked upon as the originator of the neurogenic theory. To account for the fact that the heart would continue to beat for some time after its removal from the body, it was assumed by the neurogenists that the branches of the nerves left in the substance of the heart when this organ was cut from the body were sufficient to maintain the heart-beat for some time, but Haller opposed this view and declared that the heart-muscle itself was directly stimulated by the blood that coursed through it. The older form of the neurogenic theory, however, was entirely swept away by the discovery of the brothers Weber that the vagus nerve when stimulated, instead of increasing the heart-beat brought this organ to a standstill. At about this time Remak described nerve ganglia within the substance of the heart and these have been accepted by the modern neurogenists as the nervous mechanism for the heart-beat. The fact that it is practically impossible to get adult, vertebrate heart-muscle free from nerve-cells has left the problem of the heart-beat in these animals in a situation difficult for experimental approach. That the heart-muscle in vertebrates is always a continuous one, the auricles and ventricles being connected by at least a slender bridge of muscle, favors the myogenic theory, as does also the fact that the beat can be reversed in that the ventricle can be made to contract first and the auricle afterwards. In fact the general proposition, clearly expounded by Gaskell (1900), that the vertebrate heart is a muscular tube over which a myogenic wave of contraction proceeds from the posterior to the anterior end, has much in its favor and yet there are facts enough to show that the neurogenic interpretation of the action of the adult vertebrate heart is not an impossibility.

The unfavorable conditions that surround the study of the vertebrate heart have forced investigators to seek evidence concerning the nature of the heart-beat in other animals and as a result two remarkably clear sets of cases have been obtained. The first of these is the heart of the king-crab, *Limulus*. The heart of this animal, as Carlson (1904) has pointed out, possesses the unique feature of a complete anatomical separation of nervous and muscular parts. The heart itself is a long, segmented, muscular tube situated near the dorsal line of the animal. On the dorsal face of the heart is a median nerve-cord contain-

ing ganglion-cells and connected with two parallel lateral nerve-strands that lie near the sides of the heart. This whole nervous mechanism may be dissected off from the heart, leaving this organ in other respects intact.

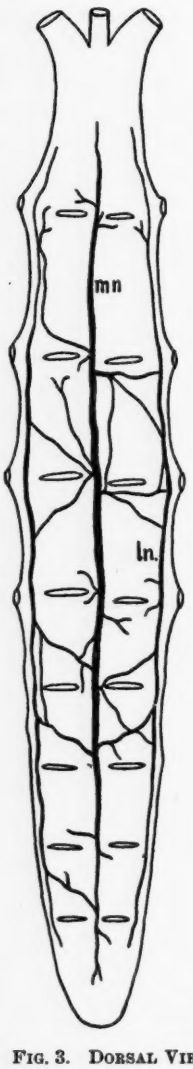

FIG. 3. DORSAL VIEW OF THE HEART OF *Limulus* (after Carlson). The anterior end is uppermost; *ln*, lateral nerve-strand; *mn*, median nerve-cord.

If a vigorous *Limulus* is opened from the dorsal side and the heart exposed, it will be seen to contract at the rate of about twenty beats per minute, and this is likely to continue under the conditions of simple exposure for some twelve to fifteen hours. If now the median nerve-cord and the lateral strands are dissected away, the heart comes to a standstill and never again shows a natural beat, though a stimulus applied directly to its substance will cause it to contract. If instead of removing the nerves, the median and lateral strands are cut through at any plane, care being taken not to injure the underlying heart-muscle, the two regions of the heart thus established beat independently and coordination of the heart as a whole is lost. If the nervous connections are left intact but the muscular heart is completely cut across in several places, the whole organ continues to beat in complete coordination. It is quite clear from these observations that the heart-beat of *Limulus* is absolutely dependent upon an extra-cardiac nervous mechanism and that this beat is carried out in exact accordance with the neurogenic theory. Since the artificial stimulation of a cardiac nerve in *Limulus* is followed by tetanus in the region of the heart under the control of this nerve, the conclusion is justified that the heart-muscle of *Limulus* is comparable rather with the skeletal muscles of this animal than with the so-called organic muscles, for skeletal muscles show tetanus when thus stimulated.

As Carlson himself remarks, however, the fact that the heart-beat of *Limulus* is neurogenic does not prove that the heart in other animals necessarily functions in a like way. In fact it is comparatively easy to point to another example in which the evidence for the myogenic beat is just as strong as that already presented for the neurogenic beat. This example is the tunicate heart. The tunicate heart, as for

instance that of *Salpa,* is a muscular tube over which peristaltic waves run from end to end. As is well known, the direction of these waves reverses from moment to moment, running for a short interval toward the visceral end of the heart, advisceral waves, and then toward the respiratory end, abvisceral waves. In *Salpa africana-maxima,* to take a single instance, according to Schultze (1901), after 16 abvisceral waves had passed over the heart in some 20 seconds, a resting period of

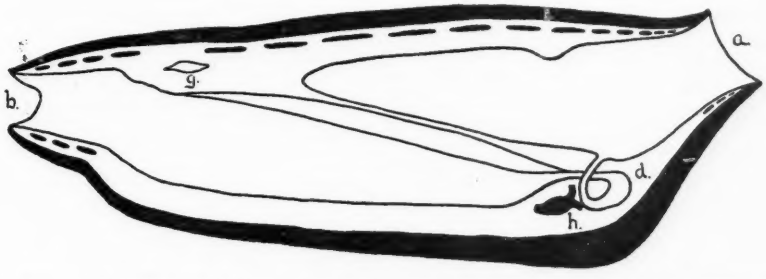

FIG. 4. SECTION OF A *Salpa* (modified from Herdman), showing the positions of the atrial aperture (*a*), branchial aperture (*b*), digestive tube (*d*), ganglion (*g*) and heart (*h*).

2 seconds ensued, whereupon 18 advisceral waves occupying 25 seconds preceded another resting period, etc. When the heart is removed from the body of a *Salpa,* it continues to beat with characteristic reversal. Stimulation of the central nervous ganglion of a normal *Salpa* has no effect upon the heart-beat, and though a removal of this organ is followed by a reduction in the rate, the same reduction is to be observed when other parts of the body than the central nervous organ are cut

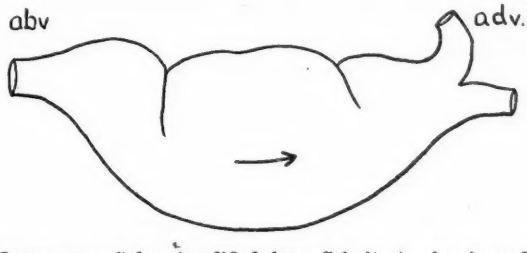

FIG. 5. HEART OF A *Salpa* (modified from Schultze), showing advisceral waves. *abv,* abvisceral end; *adv,* advisceral end.

out. Small fragments of the heart of *Salpa* also beat rhythmically when entirely isolated, a fact recently confirmed by Hunter (1903) on *Molgula,* and a most careful search of these fragments has failed to reveal nerve-cells or nerve-fibers. It seems therefore clear that the rhythmic heart-beat of the tunicates is myogenic in origin. This seems also to be true of the embryonic, vertebrate heart, for His (1891) has shown that this organ beats at a time when no trace of nervous tissue can be discovered in it.

From this general discussion it is quite evident that the cardiac muscles of different animals act in very different ways and that while some, like the heart of *Limulus*, have a neurogenic beat, others like that of the tunicates have a myogenic beat.

From this rather lengthy digression we may return to the question raised in the earlier part of this lecture, namely, the possibility of the existence of physiologically independent muscles. This I believe to have been demonstrated in part at least in the sphincter pupillæ of the lower and perhaps all vertebrates, and wholly so in the tunicate heart and the embryonic vertebrate heart. The complete freedom of such muscles from nervous control and their dependence on direct stimulation for normal action is a repetition of a process that, in my opinion, characterized all primitive muscles such as we now meet with in the sphincters of sponges. Such muscles as these sphincters I believe to represent the original and primitive elements around which the other members of the neuromuscular mechanism, the sense organs and the central nervous organs, subsequently developed. In my opinion then, effectors in the form of muscles preceded in an evolutionary sense the receptors and adjustors, and formed the centers around which these organs developed later.

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THE PREPARATION FOR THE STUDY OF MEDICINE

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Those who intend to study medicine are advised by the Medical Faculty to pay special attention to the study of Natural History, Chemistry, Physics, and the French and German languages, while in College.

This sentence of advice is contained in the catalogue of Harvard University issued in 1874. Thirty-two years later, at the dedication of the new buildings, it found more vigorous expression in the address of President Eliot.

Medical students should therefore have studied zoology and botany before beginning the study of medicine, and should have acquired some skill in the use of the scalpel and the microscope. It is absurd that anybody should begin with the human body the practise of dissection or of surgery; and, furthermore, it is wholly irrational that any young man who means to be a physician should not have mastered the elements of biology, chemistry and physics years before he enters a medical school. The mental constitution of the physician is essentially that of the naturalist; and the tastes and capacities of the naturalist reveal themselves, and, indeed, demand satisfaction long before twenty-one years of age, which is a good age for entering a medical school.

It is here assumed that these special studies form a part of the work for a bachelor's degree in arts or science, which the student has obtained before beginning his medical studies. Two groups of competent teachers of medicine dissent from this advice—those who believe that the bachelor's degree is unnecessary, since two years of special college work are sufficient; and those who consider that the degree should be required, but as a result of studies in literature, art, history and philosophy, rather than in biological science. Some physicians, therefore, send their sons to college with the advice, "Study nothing which bears upon medicine: you will have enough of that later"; and of those who have followed these directions, some have succeeded notably, both as practitioners and scientists. Because of this difference of opinion, an explanation of the relation of certain college courses to the study of medicine may be helpful to students.[1]

Zoology.—It has long been recognized by the public that zoology is not medicine. When Harvey studied the circulation of the blood, "he fell mightily in his practice." "Had anatomists only been as conversant with the dissection of the lower animals as they are with

[1] In preparing this account, assistance has been received from Drs. W. B. Cannon, L. J. Henderson, W. C. Sabine, E. E. Southard and L. W. Williams.

that of the human body," he wrote in 1628, "the matters that have hitherto kept them in a perplexity of doubt would, in my opinion, have met them freed from every kind of difficulty." However, the public was unwilling to admit that this was a proper occupation for a physician, and in 1711 Addison wrote:

> There are innumerable retainers to physic who, for want of other patients, amuse themselves with the stifling of cats in an air-pump, cutting up dogs alive, or impaling of insects on the point of a needle for microscopical observations; besides those that are employed in the gathering of weeds, and the chase of butterflies; not to mention the cockle-shell-merchants and spider-catchers.

Huxley admits that he really has never been able to learn exactly why a physician is expected to know zoology, and writes:

> If I had to choose between two physicians—one who did not know whether a whale is a fish or not, and could not tell gentian from ginger, but did understand the applications of the institutes of medicine to his art; while the other, like Talleyrand's doctor, "knew everything, even a little physic"—with all my love for breadth of culture, I should assuredly consult the former.

This is a part of Huxley's argument for excluding comparative anatomy and botany from the curriculum of medical schools. As a preliminary training for the physician he approved of them, for later he wrote:

> There can be no doubt that the future of pathology and of therapeutics, and, therefore, of practical medicine, depends upon the extent to which those who occupy themselves with these subjects are trained in the methods and impregnated with the fundamental truths of biology.

These fundamental truths are taught in college. In a general course in zoology the student should learn what an animal is, and into what great classes animals are divided. Representatives of these classes should be studied in the laboratory, and the probable relationship of one class to another, and of man to other mammals, should be considered.

The biological methods which the student should have learned in college include dissection and microscopic technic. It requires but little imagination to compare the work of two students beginning human dissection—one producing a set of instruments which he has already used, and proceeding to follow in minute detail structures similar to those which he has previously studied in the cat or rabbit; the other attempting to learn the general plan of the body and how to dissect, while he is supposed to be mastering the minutiæ of human anatomy. Practise in the dissection of vertebrates and a general knowledge of their bones, muscles, nerves, vessels and organs are essential for good work in human anatomy.

Similarly in microscopic anatomy no student can afford to try to learn how to handle a microscope while his companions, by its use, are making rapid progress in the study of human tissues. The student

who has learned how to cut and stain sections for microscopic examination will be at considerable advantage. Some medical schools give courses in this "microscopic technic," but the time is better spent in studying sections than in preparing them. It has been found by Professor Waite that the better medical schools afford less time for this subject than inferior schools. A college course in which the chief tissues are prepared and studied is therefore recommended.

Embryology, which deals with the development of the body from the egg-cell to the adult organism, is divisible into two parts. That which deals with the early stages and chiefly with lower vertebrates and the invertebrates, has grown up in zoological laboratories. That which deals with the formation of the organs and the nervous, vascular and muscular systems in mammals, and with the development of the membranes in man, has been studied especially in medical schools. It is this portion of the subject which is an invaluable aid in understanding anatomy, histology and pathology, and its study should *precede* the medical school work in these subjects. Unless this is possible in the medical school which the student is to attend, college work in embryology should be considered. Thus in the Medical Department of Johns Hopkins University, where the teachers of anatomy are distinguished for their researches in *embryology,* no medical school work in this subject is required; a college course is recommended.

Special courses in the anatomy of the nervous system are given both in college and in the medical school, though generally from different standpoints. The subject is so intricate that the college work will be found of considerable assistance.

Occasionally a college announces a course on some one group of animals, such as the protozoa, insects, or worms, as desirable in preparation for medicine. The knowledge of these groups obtained from the general course should be sufficient for a practitioner. The theoretical and statistical study of variation and heredity has only a general interest for medical students, and courses in systematic zoology are of still less importance.

The value of zoological courses as a preparation for anatomy and histology is shown in the following table, based upon the marks of the class which entered the Harvard Medical School in 1907. The table shows the number of men obtaining the grades *A* to *E*, *A* being the highest (90–100 per cent.), and *E* failure to pass (less than 50 per cent.).

	Anatomy						Histology					
Students who have taken in zoology—	A	B	C	D	E	Av. %	A	B	C	D	E	Av. %
More than two courses	0	4	7	2	1	*69*	5	6	3	0	0	*85*
Two courses	0	1	9	7	3	*53*	3	6	9	2	0	*77*
From one half to two courses	0	0	8	8	10	*49*	3	4	12	5	2	*68*
No courses	0	0	4	4	7	*45*	0	2	5	2	6	*52*

From this table it is seen that the more zoology the student has taken the better his grade in anatomy and histology. As already stated, however, the practitioner must not specialize in anatomy, and the only college courses which it seems wise to recommend to all candidates for the medical school are as follows: General zoology, dissection of vertebrates, practise in the use of the microscope and in microscopic technic, elementary embryology.

Botany.—The study of plants is clearly less intimately related to medicine than the study of animals. The peculiar importance of the bacteria, however, makes a laboratory half-course in the morphology of plants, with special reference to the fungi, very desirable. This will give the student a more comprehensive idea of these organisms than can be obtained in a medical school; it will show their relation to yeasts, moulds and other low plants, some of which are of medical importance. At the same time the student will be trained in making accurate observations of natural phenomena and in reasoning on the basis of what he has himself observed. This ability, which may be cultivated both in botanical and zoological courses, is of the utmost value to the physician.

The study of the flowering plants was once intimately associated with medicine; and the array of drugs still used, which are derived from plants, would seem to make it important. The teacher of pharmacology, however, is not seeking students familiar with medicinal foxgloves and white poppies, but desires those well trained in chemistry. The botany of flowering plants is, therefore, not recommended.

Geology.—Geology appeals irresistibly to a "naturalist," but has little value for the physician. The air, soil and water are discussed in courses on hygiene, and in connection with drainage problems and water supplies geological knowledge is important. This, however, is not a sufficient reason for recommending geology.

Chemistry.—The study of chemistry in preparation for the work of a medical school is of great importance. Accordingly both a considerable amount of theoretical chemistry and not a little laboratory work are desirable.

General descriptive inorganic chemistry and qualitative analysis are a necessary introduction to all chemical study, and must come first in any plan of chemical training; they serve to familiarize the student with the characteristics of simple chemical processes and substances, and with the more elementary chemical theories. These courses must be followed by at least a brief course in organic chemistry, because that subject, with its unique and highly important theoretical development, is absolutely essential to an understanding of certain physiological processes; and it is of such a nature that it can be assimiliated, even in its most simple form, only after a considerable period of time has been devoted to its study.

Quantitative analysis is important in another way. It gives valuable training to the hand and eye, and develops a particular form of accuracy which is required in biochemical work, and which enables the student to interpret justly the work of others.

Physical chemistry to-day contains a mass of material of the highest importance in all branches of biological science. An elementary acquaintance with it is essential for understanding such subjects as the physiology of the blood and the functional activity of the kidney and lung, since it explains the nature of solutions and the conditions governing the passage of substances through membranes.

Many medical schools require for entrance, work in general chemistry and qualitative analysis, and a few call for organic chemistry. These are essential. A half course in quantitative analysis and a half course in physical chemistry are desirable.

Physics.—Many students who are careful to take courses in biology and chemistry in preparation for medicine neglect physics entirely, or think that the elementary work done for admission to college is sufficient. A thorough college course, *with laboratory work consisting of accurate measurements,* is necessary for certain branches of medical practise and for the fundamental study, physiology. Physics is related to physiology in many ways. In studying muscular contraction the elements that constitute mechanical work and the action of levers should be known. For the study of the circulation it is necessary to understand the principles of hydraulics and the transmission of pressure in fluids; the laws of osmosis (studied in physical chemistry) aid in interpreting the diffusion of fluids between vessels and tissues. In considering the constructive and destructive changes in the body, the principle of the conservation of energy should be kept constantly in mind. To understand the maintenance of normal temperature and the changes in fever, some knowledge of the physics of heat is needed. An understanding of electricity is necessary for explaining the electrical changes produced in living tissues, and in order to stimulate tissues experimentally so that their activities may be studied. Electrical stimulation is used in treating certain diseases, and the physiological laboratory contains many pieces of electrical apparatus. The importance of the X-ray in medicine is sufficiently well known. In order to understand vision and the application of lenses to the eye, the principles of reflection and refraction must be understood. The nature of sound and its transmission through various media is similarly related to the physiology of hearing. It is a serious mistake to begin work in a modern laboratory of physiology before taking a thorough college course in general physics.

Mathematics.—The value of mathematics for medicine is indirect, since it is required chiefly in preparation for physics. The student

taking such a course in physics as has been recommended, should have had algebra, plane geometry and plane trigonometry. These courses come normally within the province of any good high school program. For advanced work in physics, solid geometry and higher mathematics are needed. For the benefit of medical students the mathematical requirement in certain special courses in physics is made as light as possible. It may be noted, however, that in the college course for future medical students outlined by Johns Hopkins University, the study of mathematics extends through two years.

Psychology.—Although psychology is a college study directly related to medicine, it appears that no medical school has yet required it for admission. A course in psychology often begins with a summary account of the nervous system and sense organs, and proceeds with the study of the states of consciousness. It discusses sensations and the nature of pain, and deals with instincts, memory, habits and the will. It gives the student a good understanding of "treatment by suggestion" and is a foundation for the study of abnormal minds, especially of hallucinations, illusions and delusions. Some knowledge of child development and an insight into sexual instincts, neurasthenia and psychasthenia are afforded by such a course. It is important for parts of physiology, pediatrics and internal medicine, and particularly for neurology and psychiatry. A half-course in psychology is therefore recommended.

French and German.—Since much of the progress of medicine is recorded in French and German publications, it is desirable, and in several schools it is required, that students should be able to read both of these languages. A beginning should be made before entering college. Courses in general literature, with practise in writing and speaking, will be found more profitable than those which are restricted to reading scientific prose. The importance of French and German in medicine is indicated by the number of periodicals in these languages for which medical libraries subscribe. The figures for the scientific libraries at the Harvard Medical School and for the Boston Medical Library, which is used largely by practitioners, are as follows:

SUBSCRIPTIONS FOR PERIODICALS

	English	French	German
Harvard Medical Libraries	110	35	109
Boston Medical Library	88	67	161
	198	102	270

Since this medical literature should be at the command of students and practitioners, and is indispensable for investigators, it is necessary to be able to read both French and German.

Other Foreign Languages.—Although important medical articles

are published in Italian, and to a less extent in Spanish and other modern European languages, they are not so numerous as to justify a study of these languages. Latin is required for admission to certain medical schools, "in order to enable the student the more rapidly to master scientific and medical nomenclature." The international anatomical nomenclature is now entirely Latin and many of its terms are employed as English words. It is, therefore, very desirable that a student of medicine should have studied Latin as a part of his preparation for college. Greek is of much less importance, although it has supplied many barbarous medical terms.

English.—Although some students believe that in an examination in anatomy they should be marked upon anatomy alone, and not upon English, this is impossible. Every examiner, as well as every intelligent patient, will judge of the physician, in part at least, by his manner of expression. In a lot of examination books which had been marked in the usual way, there were a few with the grade *A*, and in none of these was there an example of strikingly bad English. The first book of low grade (60 per cent.) which was taken up, contained the following statement:

> Voluntary striated muscle, developed differently, than smooth and cardiac, that coming from mesenchyma, this from somite or segments, has a definite cell membrane sarcolemma, which gives off fibers, its nucleus is found at the periphery.

It is useless to assert that clear and well-ordered anatomical knowledge exists in a mind which can not express it.

The study of English literature in college is to be recommended not only for its utilitarian value, but as a source of recreation and diversion from specialized scientific studies. There may be a few medical students who need the advice which Holmes gave to the young practitioner: "Do not linger by the enchanted streams of literature," but many more should heed the warning—"Do not let your literary life become a memory—a reminiscence." Unfortunately there are those who enter medicine with nothing on which to found a literary reminiscence.

Drawing.—The principles of drawing are taught in connection with courses in the fine arts or in architecture. Accuracy of observation may be developed in such courses, for no sooner does one begin to draw or model an object than attention is called to many details otherwise overlooked. For this reason drawing is required in studying anatomy, especially microscopic anatomy, in certain medical schools; and inability to draw seems to many students a justification for deficiencies in these subjects. To be sure, their professors are often in a similar predicament. Ruskin says:

That Professor Tyndall is unable to draw anything as seen from anywhere, I observe to be a matter of much self-congratulation to him; such inability serving farther to establish the sense of his proud position as a man of science, above us poor artists who labor under the disadvantage of being able with some accuracy to see, and with some fidelity to represent, what we wish to talk about.

If a course in art can develop this ability, it should be considered by medical students. To perceive accurately is not only a source of great enjoyment in itself, but to a certain extent it is an aid to the practising physician. One medical school in the United States recommends drawing for admission, and another provides instruction in anatomical drawing as an elective course.[2]

College Physiology and Hygiene.—Some colleges offer courses in physiology which are dilute presentations of medical school work. Thus, in one course, the student may be taught something of human anatomy, physiology, hygiene and medical bacteriology, all of which may be useful for those who are not intending to study medicine. It is wholly undesirable for the medical student to take time from other college work for the sake of such courses.

The Value of Research.—Some teachers believe that the original investigation of a subject in science, since it compels the student to think for himself and to depend upon his own observations, is worth several regular courses as a preparation for medical study. Certain researches, moreover, are not difficult. A study of the variation in the number of rays in the daisy, or of spinal anomalies in the salamander, might be made by an undergraduate if specially taught for this purpose. Such researches, however, are generally at the expense of fundamental education, and "researchlings" are not good students of elementary subjects.

Summary of Recommendations.—In the preceding pages it has been recommended that the medical student should have studied Latin, French, German, mathematics, physics and drawing in preparation for college; and that in college he should elect courses in zoology, botany, chemistry, physics, psychology, English, French and German, since these studies will be of direct value in connection with his work in the medical school. Between two and three years will be required for the recommended studies, but some time will be free for philosophy, history and political economy. These subjects are named since they

[2] Since this was written, President Eliot has referred to the advantages of studying drawing in the preparatory schools, as follows: "A university student who enters on the subject of botany or zoology is really crippled unless he can draw. He will make much slower progress; and will not have the best means of recording what he sees. And yet it is only a small percentage of the young men who now come to Harvard College that have any capacity for drawing. They have never had any opportunity to acquire any artistic skill."—Address to Graduates of the Massachusetts Normal Art School, April, 1909.

are the ones not already discussed which were formerly required for the bachelor's degree, and which are now considered by some to be an essential part of a good education. Three full years of college work which have included such courses as have been recommended, and which have led to the bachelor's degree, will be accepted as a good preparation by any medical school in the United States.

The Value of the Bachelor's Degree.—The value of the bachelor's degree for students of medicine is now generally recognized. A few medical schools require it and many recommend it. Students should, however, be warned against believing that the degree may be earned by two years of college work. This low standard, thinly disguised by the fact that the degree is not given the student until he has spent two years in the medical school, has been adopted by many colleges and is sometimes announced with considerable satisfaction, as follows:

> The incalculable advantages of such a combination course must commend themselves at a glance, alike to would-be medical students who realize the value of an academic degree to the physician, and to candidates for an academic degree who contemplate a medical career and hesitate before the length of time demanded by its preparatory work.

Not only should protest be made against reducing the college work to two years, but much might be said in favor of four years, leading to the master's degree. In the Harvard Faculty of Medicine there are fifteen men who graduated from college since 1890. Two of these are doctors of philosophy; of the remaining thirteen doctors of medicine, six are masters of arts. The positions held by the six masters of arts and the seven bachelors of arts, respectively, are as follows:

	A.M.	A.B.
Professors	2	—
Assistant Professors	4	2
Demonstrators and Instructors	—	5

Since this list happens to include few practitioners, it may be noted that the college classes of '88–'90 supplied the faculty with six members, all practitioners; five of the six are masters of arts.

Not long ago, American medical schools received freely students with no college training. Scattered through the classes there were some who, without being required to do so, had obtained a college degree. The success of these men has been so notable that the requirements for admission are rapidly becoming more stringent. At Columbia University the effect of demanding one year of college work has been to eliminate that stratum of medical students described by Professor Wood as the submerged tenth.[3] Most of the good schools now require two

[3] Professor Wood advocates a low entrance requirement in the following remarkable statement. "The poor man, who has neither time nor money for long preparation, can enter and compete on an equal footing with the children of the rich. . . . If he does not survive the first year, well and good, no great harm has been done. . . ."

years of college work, and the student is tempted to regard this as ample preparation.[4] The community meanwhile is seeking not younger but abler physicians. A shorter preparation than that which was obtained by many leading practitioners of the present generation is not likely to make their successors more efficient.

The Value of Scientific Preparation.—There are some physicians who believe that the preparation which has here been recommended produces scientists and not practitioners. It is clear, however, that a single course in physiology, even a very thorough one, does not make a physiologist. The professor of embryology who addressed the students who had just finished his course as "fellow embryologists" was greeted with a roar of laughter. Some of those who know that scientists are not produced by the medical school course still assert that it develops an undesirable type of scientific practitioner. A graduating class has recently been told that "At the bedside science is sometimes a hindrance." Scientific knowledge is often contrasted with common sense and sympathetic humanity, as if they were incompatible and the patient must choose between them. The medicinal effect of a merry heart, known since the time of Solomon, has been rediscovered with great eclat, and the physician whom Holmes described as having a smile "commonly reckoned as being worth five thousand dollars a year to him" has his successors. The character of a physician is unquestionably of great importance, yet medicine is not an art of which "haply we know somewhat more than we know." No condemnation is too severe for a physician who, without adequate knowledge of the medical sciences, attends his patient with self-confidence and a genial smile.

The college student may well be assured that the way to financial and professional success in medicine is through long and careful preparation. In this great pursuit he will not become narrow. He will develop what Dr. James Jackson long ago described as "a mind *liberalized by scientific studies.*" If he loses a certain breadth of culture because of specialization, still, as Cardinal Newman has said, "the advantage of the community is nearly in inverse ratio with his own."

[4] A caution against this has recently been published by the dean of the medical courses at the University of Chicago. He says: "No device for curtailing the amount of his preparation should be sought or advised for students who can go 'the whole road' (that is, obtain a regular course and medical degree) within the age limit of twenty-seven or twenty-eight." The announcement of the University of Chicago contains the italicized statement: "Every student should complete a four-years' college course before entering the Medical School if his age and other circumstances make it possible for him to do so."

DARWINISM IN THE THEORY OF SOCIAL EVOLUTION[1]

By FRANKLIN H. GIDDINGS, LL.D.

REVOLUTIONIZING as the life work of Charles Darwin was in the fields of biology and psychology, one may doubt if his writings disturbed the intellectual peace anywhere more profoundly than in the "Sweet Jerusalem" of pre-Darwinian social philosophy. Borrowing a shocking thought from the Rev. Thomas Robert Malthus, Mr. Darwin, in due course of time, gave it back to Malthusians and Godwinites, to Ricardians and Ruskinites, to Benthamites and Owenites, with a new and terrific voltage.

Nine years before "The Origin of Species" was published, Herbert Spencer, in the concluding chapters of "Social Statics," had offered an explanation of society in terms of a progressive human nature, adapting itself to changing conditions of life. These chapters are the germ of that inclusive conception and theory of evolution which were elaborated in the ten volumes of the "Synthetic Philosophy." Five years later, or four years before "The Origin of Species" saw the light, Mr. Spencer, in the first edition of his "Principles of Psychology," set forth an original interpretation of life, including mental and social life, as a correspondence of internal relations to external relations, initiated and directed by the external relations. Finally, in April, 1857, Mr. Spencer published, in *The Westminster Review*, his epoch-marking paper on "Progress: Its Law and Cause," in which his famous law of evolution was partially formulated, and evolution was declared to be the process of the universe and of all that it contains.

Mr. Spencer thus had seen evolution in its whole extent, as adaptation and differentiation. He had not yet mentally grasped the universal redistribution of energy and matter, wherein every finite aggregate of material units, radiating energy into surrounding space, or absorbing energy therefrom, draws itself together in order-making coherence, or distributes itself abroad in riotous disintegration. That universal equilibration, which in fact is the beginning and the end of evolution, was the aspect of the world which in thought Mr. Spencer arrived at last of all.

It is not given to any one human intellect to discover all truth, and there is more in evolution than even Mr. Spencer perceived, either at the beginning of his great work, or in the fulness of his powers. Intent upon the broader aspects of cosmic transformation, his mind did not

[1] A lecture in the course on "Charles Darwin and his Influence on Science," delivered at Columbia University, April 16, 1909.

seize upon certain implications of universal rearrangement. In the concrete world of living organisms, equilibration becomes the relentless struggle for existence, in which the weakest go to the wall. Natural selection follows. It was this intensely concrete aspect that Mr. Darwin saw, and intellectually mastered.

The distinction here indicated between evolution as a universal process, comprehensively described by Spencer, and Darwinism, or Mr. Darwin's account of one vitally important and concrete phase of that process, has often been noted, and is usually observed by careful writers. It is of particular importance in any discussion of social evolution. To indicate how far our theories of social origins, our philosophies of history and of human institutions, have become not only evolutionist, in the Spencerian sense of the word, but also Darwinian, is the purpose of my lecture this afternoon.

It was not until the publication of "The Descent of Man," in 1871, when controversy over "The Origin of Species" had raged through twelve years of intellectual tempest, that the full significance of natural selection for the doctrine of human progress was apprehended by the scientific world. Mr. Spencer saw it when "The Origin of Species" appeared. Mr. Darwin himself had perceived that he must offer a credible explanation of the paradox that a ruthless struggle for existence yields the peaceable fruits of righteousness. But it was neither Mr. Spencer, nor Mr. Darwin, who first recognized the specific phase of the life struggle in which the clue to the mystery might be sought. The gifted thinker who made that discovery was Walter Bagehot, editor of the London *Economist,* whose little book on "Physics and Politics, or Thoughts on the Application of the Principles of Natural Selection and Inheritance to Political Society," was published, first as a series of articles in *The Fortnightly Review,* beginning in November, 1867. Mr. Darwin rightly calls these articles "remarkable." Revised and put together in book form they made a volume of only two hundred and twenty-three small pages in large type, but no more original, brilliant or, as far as it goes, satisfactory examination of the deeper problems of social causation has ever been offered from that day until now. It anticipated much that is most valuable in later exposition.

In the "Social Statics," Mr. Spencer had shown that primitive man, subsisting upon inferior species and contending with them for standing room and safety, necessarily developed a human nature adapted to the task of slaughter, cruel, therefore, and unscrupulous; but that triumphant posterity, inheriting a subjugated world, and no longer bound to kill, might become sympathetic enough to cooperate successfully in peaceful activities. The exact relation, however, of this process to group formation or to the collective activity of a cooperating group when formed, Mr. Spencer at this time certainly did not see. For, incredible though it may seem, Mr. Spencer did not at this time so much

as make note of the terrific struggles for control of food-getting opportunities that occur among individuals or between groups of the same species, variety or race. Conflict among men of the same cultural attainments Mr. Spencer thought of only as prompted by surviving savage instincts, engendered by predatory habits, in the lawless youth of the race.

It was specifically the phenomena of group solidarity and of collective conflict, in distinction from a merely individual struggle for existence, which Mr. Bagehot selected for examination, and his mind penetrated directly to the essential conditions of the problem. He said:

> The progress of *man* requires the cooperation of *men* for its development. . . . The first principle of the subject is that man can only make progress in "cooperative groups"; I might say tribes and nations, but I use the less common word because few people would at once see that tribes and nations *are* cooperative groups, and that it is their being so which makes their value; that unless you can make a strong cooperative bond, your society will be conquered and killed out by some other society which has such a bond; and the second principle is that the members of such a group should be similar enough to one another to cooperate easily and readily together. The cooperation in all such cases depends on a *felt union* of heart and spirit; and this is only felt when there is a great degree of real likeness in mind and feeling, however that likeness may have been attained.[2]

Addressing himself to the question how the necessary likeness in mind and feeling are produced, Mr. Bagehot answers: By one of the most terrible tyrannies ever known among men, namely, the authority of customary law; and in accounting for the origin and force of custom, he develops a theory of the function of imitation which anticipates much, but by no means all, of the sociological theory of Gabriel Tarde. Custom, however, tends to create a degree of similarity among social units, and an unchanging way of life, fatal to further progress. To reintroduce and to maintain certain possibilities and tendencies toward variation is, as Bagehot sees the process, one of the chief uses of conflict. Social evolution thus proceeds through the conflict of antagonistic tendencies, on the one hand toward uniformity and solidarity; on the other hand toward variation and individuality. In some groups, one of these tendencies predominates. Contending together, group with group, in the struggle for existence, those groups survive in which the balancing of these tendencies secures the greatest group efficiency. It is not too much to say that in this interpretation, Mr. Bagehot arrived at conclusions which to-day we recognize as belonging to the theoretical core of a scientific sociology.

Mr. Darwin, in those chapters of "The Descent of Man" in which he treats of the origin of social instincts and the moral faculties, adopts in substance the conclusions of Mr. Bagehot, and with his keen sense for what is essential, lays emphasis upon four facts, namely: (1) the

[2] "Physics and Politics," pp. 212, 213.

importance of group or tribal cohesion as a factor of success in inter-tribal struggle, (2) the importance of sympathy as a factor in group cohesion, (3) the importance of mutual fidelity and unselfish courage, and (4) the great part played by sensitiveness to praise and blame in developing both unselfish courage and fidelity. In terms of these four facts, Mr. Darwin finds an answer to the question, how, within the conditions fixed by a struggle for existence, social and moral qualities could tend slowly to advance and to be diffused throughout the world.

That the studies of both Mr. Bagehot and Mr. Darwin left much still to be said on the subject of group feeling and cooperative solidarity was shown when, in 1890, Prince Peter Alekseevich Kropotkin published in *The Nineteenth Century* his fascinating articles on "Mutual Aid among Animals," afterwards supplemented by studies of mutual aid among savages and among barbarians. These articles contained nothing essentially new in theory, but they contributed to our knowledge an immense mass of facts demonstrating how great has been the part played by sympathy and helpfulness in the struggle for existence, and how inadequate would be any interpretation of natural selection which accounted for it wholly in terms of superior strength, cruelty and cunning.

Mr. Darwin never claimed to offer an adequate explanation of the variations which natural selection preserves or rejects. He sometimes took them for granted, he sometimes spoke of them as accidental or fortuitous. He would have been the last to pretend that he had told us all that we should like to know about the beginnings of sympathy or of sensitiveness to praise or blame. But, starting from sympathy and the desire for approval as traits that may actually be observed among gregarious creatures, and that presumably have somehow had a natural origin, Darwin and Kropotkin convincingly demonstrate that groups possessing these qualities have a certain advantage in the struggle for life.

To account more fully for the origins, in distinction from the natural selection of the social qualities, was the problem that Mr. John Fiske attacked in his theory of the effects of prolonged infancy, first published in the *North American Review* of October, 1873,[3] and a year later in the "Outlines of Cosmic Philosophy." Fiske discriminates between "gregariousness" and "sociality," without, however, sufficiently analyzing the one or the other, or quite defining the difference. By sociality he seems to mean a relatively high development of sympathy, affection and loyalty to kindred or comrades. He argues that sociality has its origin in small and permanent family groups. These are not necessarily monogamous at first. They may be polygamous or polyandrian, and may broaden out into clans. But they must be more enduring than matings observed in the merely gregarious herd.

[3] Under the title: "The Progress from Brute to Man."

The cause of both definiteness and permanence he finds in the prolongation of infancy, necessitating a relatively long-continued parental care of offspring. The relations so established among near kindred have conserved and strengthened the feelings of affection and the sense of solidarity. Mr. Darwin recognized Mr. Fiske's theory as an important contribution to the subject. It must be said in criticism, however, that Mr. Fiske did not see all the implications of prolonged infancy, or develop his theory into all its possibilities. Admitting that the prolongation of infancy was probably a factor in the evolution of stable family relationships, and therefore played a part in strengthening the social sentiments, we must remember that the actual social life and solidarity of the gregarious group was probably a chief cause of the prolongation of infancy itself. Demanding, as it did, a relatively keen exercise of brain and nervous system in communication, imitation and cooperation, it operated to select for survival those individuals that varied in the direction of high brain power and its correlated long infancy. But this is to say that society was a factor in the evolution of man before man became a factor in the evolution of society, and the difference is important.

Moreover, Mr. Fiske's theory no more explained the actual origins of sympathy and cooperation than Bagehot's and Darwin's theories had done. Neither, for that matter, did Sutherland's account of "The Origin and Growth of the Moral Instinct,"[4] although Sutherland got somewhat farther back when he called attention to the reaction of parental care of offspring upon the evolution of ganglia making up the sympathetic nervous system.

At this stage the Darwinian interpretation of social origins had arrived when, in 1894, there was published a work which had an almost sensational reception. Hailed as a new gospel by minds desiring above all things to find some solid ground for religious convictions that had seemingly suffered violence in the course of evolutionist warfare, this book by scientific critics was treated with scant respect. These critics, I venture to think, were in error. For, in fact, the "Social Evolution" of Benjamin Kidd raised a profoundly important question, and gave an answer to it which, while half wrong, was probably half right, and the half that was right was a real and important contribution to knowledge. Stated in the fewest possible words, Mr. Kidd's query was this:

Since natural selection saves the few and kills the many, why does not the great majority of mankind try to curb competition and put an end to progress? Thus presented, Mr. Kidd's question is the radical and fearless form of a question which socialism asks in a form that, by comparison, is conservative and half-hearted. And Mr. Kidd's answer,

[4] Published in 1898, a worthy product of Australian scholarship, which its author described as largely a detailed expansion of the fourth and fifth chapters of "The Descent of Man."

not so much as tainted with socialism, is as fearless as his question. Progress has no rational sanction. It is irrational and, from the standpoint of reason, absurd. Man goes on multiplying, competing, fighting and making progress because he is not rational and has no desire to be. He lives not by reason, but by faith. He crucifies and kills himself to improve the race, not because he is scientific, but because he is religious.

Perhaps it was because Mr. Kidd's thesis was paradoxical, that theologians found in it something tangible and scientific men did not. It should be possible now to look back upon it without prejudice. On the face of it, it is an obvious fallacy, but back of fallacy lies a truth.

The fallacy consists in an unwarranted assumption that individuals and families marked for extermination in the struggle for existence are, in their own lifetime, aware of their impending doom. Let us suppose that, of one hundred families now flourishing, ninety will become extinct in the tenth generation, their places being filled by a corresponding number of new families branching from the one successful line. This would be natural selection at a rapid rate. Yet to maintain this rate, only ten families have to drop out in any one generation, and ten new ones to appear. This means that, at any given time, a ninety per cent. majority of all persons at the moment living have an expectation of further life, the termination of which can not be foreseen. The large majority, therefore, at any given time existing think of themselves not as the unfit that must perish, but rather as the fit selected to survive.

This way of stating the problem, however, brings us face to face with a peculiarly interesting truth, for the apprehension of which we rightly may give generous credit to Mr. Kidd. Obviously, while no family stock or race at any time existing can certainly know, or, while it remains still vigorous, find sufficient ground to believe that it is doomed to perish, neither can it certainly know that it is indefinitely to survive. It does live, struggle, plan and achieve not altogether by knowledge or by reason, but also in part by faith. It hopes, it expects to endure. It believes in its future.

This faith by which a race, a family, or an individual lives, is not anti-rational, nor yet super-rational. It is rather sub-rational or proto-rational. It is deeper, more elemental than reason—a fact of instinct and feeling. It is *faith in the possibilities of life,* born of actual survival in the struggle for existence. The question, therefore, which Mr. Kidd should have asked, and which we, reviewing his work, must ask in his stead, is this: May we identify our elemental faith in the possibilities of life with the tremendous social phenomenon of religion, which, in all the ages of man's progress, has been one of his supreme interests? Shall we perhaps find that, when reduced to its lowest terms, to its essential principle, religion is not, as has been supposed, a belief in gods, or in a supernatural, in any way conceived, but is rather

that primordial faith in the possibilities of life which was born, and generation after generation is re-born, of success in the struggle for existence; which may gather about itself all manner of supplementary beliefs, including a belief in spirits and in gods, but which will persist as the deepest and strongest motive of life after science has stripped away from it all its mystical and theological accretions? I hope to show that such is the fact. So believing, I accept as a positive contribution to the theory of human evolution Mr. Kidd's proposition that religion, a thing deeper and more elemental than reason, has been a chief factor in social evolution.

The mention of socialism, when referring to the theories of Benjamin Kidd, may serve to remind us of two further contributions to the Darwinian theory of society still to be mentioned. The Marxian socialist who has taken trouble to read Mr. William Hurrell Mallock's American lectures on socialism,[5] will not be disposed to admit that Mr. Mallock is a competent student of social phenomena. Before passing judgment, however, he should examine Mr. Mallock's "Aristocracy and Evolution," a suggestive and really important work, published in 1898. In this book Mr. Mallock rises above his habit of literary trifling, and digs somewhat below his prejudices, to examine not only fairly, but also cogently, and with illumination, the phenomenon of personal ability as a factor of social achievement. Distinguishing between a struggle for existence merely, and a struggle for domination, he contends that progress in any legitimate sense of the word is attributable to the struggle for domination. No one, I think, can go far in sociological study without seeing that this is a significant distinction for purposes of historical interpretation.

One need not, however, draw the conclusion that democracy is necessarily antagonistic to progress, as Mr. Mallock does. He says:

> The human race progresses because and when the strongest human powers and the highest human faculties lead it; such powers and faculties are embodied in and monopolized by a minority of exceptional men; these men enable the majority to progress, only on condition that the majority submit themselves to their control.[6]

No student of social evolution would be less likely to dispute these propositions than Mr. Francis Galton, who, in fact, in his studies of natural inheritance and hereditary genius, has done more than any other investigator to establish them on a broad inductive basis. And after Mr. Galton, no investigator has made more valuable studies in this field than Mr. Karl Pearson, and no one more unreservedly than he accepts the conclusion that superiority is necessary to social advance and that personal superiority is a fact of heredity. Yet Mr. Pearson con-

[5] Delivered in 1906; published 1907 as "A Critical Examination of Socialism."

[6] "Aristocracy and Evolution," p. 379.

tends that to add artificial advantage to natural superiority is fatal, because superiority can not be maintained unless the herd, as well as the superior individual, is carefully looked after and improved. The superiority that achieves leadership and domination is usually the power to do some particular thing exceptionally well. It is extreme individuation, and it often is purchased at the cost of race vitality. It is as necessary to maintain the one as to develop the other. Mr. Pearson therefore finds the socialistic program not incompatible with continuing progress by selection and inheritance.[7]

"To 'wage war against natural inequality' is clearly a *reductio ad absurdum* of the socialistic doctrine. So far as I understand the views of the more active socialists of to-day, they fully recognize that the better posts, the more lucrative and comfortable berths, must always go to the more efficient and more productive workers, and that it is for the welfare of society that it should be so. Socialists, however, propose to limit within healthy bounds the rewards of natural superiority and the advantages of *artificial* inequality. The victory of the more capable, or the more fortunate, must not involve such a defeat of the less capable, or the less fortunate, that social stability is endangered by the misery produced. At the present time a failure of the harvest in Russia and America simultaneously, or a war with a first-class European power, would probably break up our social system altogether. We should be crushed in the extra-group struggle for existence, because we have given too much play to intra-group competition, because we have proceeded on the assumption that it is better to have a few prize cattle among innumerable lean kine than a decently-bred and properly-fed herd with no expectations at Smithfield."

From this too brief account of the applications thus far made of Darwinian theory to the problems presented by social relationships, including human institutions, we may turn to the question of further scientific possibilities in this direction. It will have been noted that the theories reviewed are not as they now stand entirely consistent with one another, and that none of them carries explanation back to the actual beginnings and causes of group formation. Perhaps if we could more adequately account, in terms of the struggle for existence, for actual social origins, and for successive stages of social evolution, the various fragments of theory which we now possess would fall into orderly correlation.

Possibly also the most promising starting point for any new attempt to achieve these ends may be found in a careful scrutiny of what is involved in the struggle for existence itself. Close readers of "The Origin of Species" know that although Mr. Darwin, when employing the phrase "a struggle for existence," usually meant by it a struggle for subsistence, he uses it also to mean a struggle with the physical conditions of life, to which an organism that would survive must be or

[7] "The Chances of Death," Vol. I., pp. 112, 113. In view of the apprehensions just now so freely expressed in England, it is, I think, worth while to quote the exact words in which Mr. Pearson more than ten years ago summarized his argument:

must become adapted. "Two canine animals in a time of dearth," he remarks, "may truly be said to struggle with each other which shall get food and live. But a plant on the edge of a desert is said to struggle for life against the drought, though more properly it should be said to be dependent on the moisture."[8] Also, "climate plays an important part in determining the average numbers of a species, and periodical seasons of extreme cold or drought seem to be the most effective of all checks."[9] Yet further, "when we reach the Arctic regions, or snow capped summits, or absolute deserts, the struggle for life is almost exclusively with the elements."[10] Again, Mr. Darwin often means, not a struggle for food or against the elements, but a struggle to avoid being converted into food. "Very frequently," he writes, "it is not the obtaining of food, but the serving as prey to other animals, which determines the average numbers of a species."[11] And some of his most fascinating pages deal with the variations, such as protective markings, colorings and habits, which are helpful in the mere struggle for safety. Once more, in those paragraphs in "The Descent of Man" already referred to, in which Mr. Darwin recognizes the utility of group solidarity, he, by implication, takes account of a struggle on the part of associating individuals to adjust their interests and their activities to one another in such wise that group life may be maintained.

If, then, it is legitimate to use the term, "struggle for existence," "in a large and metaphorical sense," as Mr. Darwin says his practise is,[12] the struggle itself obviously consists of four distinct and specific struggles, namely: (1) *the struggle for safety;* (2) *the struggle for subsistence;* (3) *the struggle for adaptation* by every organism to the objective conditions of its life, and, (4) *the struggle for adjustment,* by group-living individuals to one another.

And this large use of the term is legitimate in fact. Mr. Darwin's only mistake was in calling it "metaphorical." For, as Karl Pearson has pointed out, "the true measure of natural selection is a selective death rate,"[13] and any circumstance, whether it be danger, or scarcity of food, or non-adaptation to physical conditions, or mal-adjustment of associating individuals to one another, which affects the selective death rate, is a factor in the struggle for existence.

If so much be granted, a number of difficult questions get a real illumination. What are the true relations of esthetic and economic, of ethical and social phenomena to one another, and to life in its wide inclusiveness? What, especially, is the precise point of departure of

[8] "The Origin of Species," p. 78.

[9] *Ibid.*, p. 84.

[10] *Ibid.*, p. 85.

[11] *Ibid.*, p. 84.

[12] *Ibid.*, p. 78.

[13] Essay on "Reproductive Selection" in "The Chances of Death and Other Studies in Evolution," Vol. I., p. 63.

social evolution from all that precedes it and prepares for it? And what is the precise discrimination needful of things social from things merely organic or psychological? The modes and the phases of the struggle for existence suggest intelligible answers.

Quite obviously the struggle for safety is the shaping cause of our esthetic life, the life of sensitiveness and of appreciation. On this point Mr. Darwin's data and conclusions are exhaustive. Instant reaction, if the organism is unconscious, discrimination if it is conscious, and due estimate of light and shade, of color and form, of sound and of pressure, in all their objective degrees and proportions, dissonances and harmonies—these are the readiness and the responsiveness requisite for safety from each instant of life to the next. Obviously, moreover, the esthetic life, so understood, is elemental and precedent. For an organism must in fact survive from moment to moment before it can have further need or power, even to eat.

The struggle for subsistence initiates and broadens into the economic life. The struggle for adaptation becomes the ethical life. For adaptation, in its beginnings a mere taking on or perfecting of useful characters, develops, in time, into self-control, self-direction and self-shaping.

Between adaptation and adjustment, no distinction whatever has been made by a majority of evolutionist writers. Spencer uses the word "adjustment" to include all that biologists and psychologists commonly mean by adaptation. Yet the two things are not at all the same. The struggles which they involve are not identical struggles, and, for the purposes of sociological theory, the distinction is of fundamental importance.

Adaptation—which, as it goes on, widens into and includes the ethical life, at first is a mere conforming of the organism through variation, selection and inheritance, to the physical conditions under which it happens to live; that is to say, to altitude, temperature, light or darkness, dryness or moisture, enemies, food supply, and so on. Through adaptation, and because non-adaptation means extinction, the individuals of any given species congregated and dwelling in any given region where adequate food supplies are found become increasingly alike, and the first two conditions of social life, as Mr. Bagehot rightly explained it, namely, grouping and substantial resemblance, are provided. But, since they are alike, individuals of the same variety or race, so brought together in one habitat, necessarily want the same things, and in like ways try to get them. They may compete in obtaining those things which each is able to get by his own efforts, or they may combine their efforts to obtain those things that no one could get unaided. In either case their interests and activities sooner or later must fall into adjustment. And, since any failure of adjustment may be as fatal as non-adaptation or starvation, there will be a struggle, at

first perhaps unconscious, but in course of time becoming conscious, to maintain adjustment and to perfect it. This struggle for adjustment is the beginning of social life and is the differentiating mark of all true social phenomena.

Or, to put the matter in slightly different words, while the struggle for safety develops the esthetic life, and the struggle for subsistence becomes the economic life, and the struggle for adaptation broadens into the ethical life, the struggle of resembling creatures to adjust their similar adaptations to one another, is the beginning and the continuing process of the social life.

Through success in all these struggles, and not in any one alone, there results a survival of the fit, that is, of those organisms that are so equipped with proper parts and habits that they on the whole fit into and conform to all the essential conditions of life provided by the environment in which they are forced or elect to dwell.

Holding their own in such unremitting and remorseless contests, those among them in whom consciousness has awakened, inevitably come to feel a certain sense of vital adequacy, a will and power to live, and an assurance of unexhausted opportunity. There is born in them a faith, inarticulate at first but effective, in the possibilities of life. Impelled by this faith and equipped with social instinct, man, outstripping all other creatures, presses forward into the wider conflicts of a *collective* struggle for existence.

Here a word must be said about the subjective aspect of society, which, in its objective aspect, as we have seen, is merely the struggle and process of adjustment. What is the relation of adjustment to sympathy and to understanding, to communication and to concerted purpose, to the evolution of a social constraint through which the community controls and shapes the individual, to cooperation and to social organization?

These questions are not really so difficult as some others. We have seen that adjustment arises because like creatures want the same things and in like ways try to get them. Now, wanting the same things, and trying in like ways to get them, are essentially psychological phenomena, and under analysis they resolve into one elementary phenomenon in particular, namely, like response to the same, or to similar, or to common stimulation. Responding in like ways to the same, or to common stimulation, associating individuals, acting upon one another also by suggestion and example, and imitating one another in a thousand ways, have identical feelings and develop identical or closely resembling ideas. Sympathy and understanding, as the psychologist explains, are by-products of all these things. Sympathy and understanding, supplemented by communication, and backed up by the enormous mass of common feelings and ideas, find expression in those common and usual

ways of doing things, those norms and elements of custom which Professor Sumner has so admirably named "the folkways."

Folkways, customs, mores, enforced by collective instinct and feeling, constrain the individual. They become that "most terrible of all tyrannies known to man," of which Mr. Bagehot wrote. But that tyranny, as Bagehot demonstrated, perfects the group in the unity of essential likeness, and in the consciousness of likeness, and holds it together in the bonds of solidarity. Conscious of the usefulness of solidarity, the group, as it becomes self-conscious, endeavors by definite policies so far to prescribe individual conduct as to control and limit variation from type. Society thus becomes a type-conforming group of associates, endeavoring, by self-instituted discipline, to maintain, as a type, its distinctive characteristics.

To observe the successive stages, and the complications of man's collective struggle for existence, is to examine the evolution of tribal society and to follow the history of civilization—a large undertaking. The few words that I have to offer upon these subjects at the present time will refer only to some of the relations that seem to hold between very general influences, on the one hand, and some of the larger results, on the other.

Group safety is the first consideration. It is attained through unity of action, a prerequisite of which is the sense of solidarity. To the making of solidarity, everything that we are in the habit of calling conventionality contributes. Not only the fundamentally important conventions of language, but also those of manners, of costume and of ceremonial have here an essential function.

Doubtless it is at this initial stage of the collective struggle, when life is a day by day hazard, and man's overmastering emotion is dread, that religion acquires its first intellectual coefficient. Since Edward B. Tylor developed his theory of a primitive animism, much new light has been thrown upon the earliest religious notions of the race. The new discoveries have not convinced us that animism was, indeed, the actual beginning of religion, much less have they proven that the ghost theory of Spencer's exposition was. On the contrary, research apparently has demonstrated that religion, before it was spiritistic or even animistic, was quite impersonal. It was a recognition and an ever-present dread of external power, conceived merely as strength or might. Mana, or Manitou, was not the Great Spirit of the missionary's imagination; it was merely The Great Big, The Great Mighty, The Great Dreadful, and the earlier way of establishing working relations with external might lay not through sacrifice or prayer, but through the ingenious trickery of the black art, that is to say, of magic.

But was even magic the very first mode of worship? Speaking for myself only, I doubt it. In the folkways and folklore of every people

we find, deep down in the stratum, the arts of augery, of divination, of fortune telling. In these, I suspect, we discover the earliest religious ideas and practises, as distinguished from religious feeling or faith. Before man thought of fooling, or tricking, or bribing, or importuning the powers that control his fate, he tried simply to find out what they were likely to do to him. He tried to learn whether and how far he was safe, to foresee his fate.

It has been in view of such considerations as these, and especially because of the strong probability that religion was impersonal before it became animistic, that I have thought it legitimate to identify religion in its ultimate essence or principle, with that elementary and primordial faith in the possibilities of life which springs from success in the struggle for existence.

Collective economic effort takes at first the form of a group exploitation of various natural sources of subsistence. Each horde becomes identified with a particular region or hunting-ground, and sometimes with a particular kind of food. The notion arises that the human group and its food, plant or animal, had a common origin and are now kindred. Magic is developed as the means relied on to preserve and to increase the food supply. This idea and resulting practise constitute totemism, which differentiates primitive communities into economic groups and into kinship divisions.

Within each group, the adaptation of individuals to prevailing life conditions is furthered by the folkways, imposing upon every person a common morality, and, through initiation ceremonies, or other formidable disciplines, developing in him some power of self-control. From experiences of discipline received and imparted, and of self-mastery, springs a crude theory of personal power or agency. Here, probably, is the true origin of animism as a theory of causation, and from this point religion tends to become animistic.

The ever-recurring conflicts between group and group call forth leadership, establish the simpler forms of personal government and mark out the elementary social distinctions. It is now that ideas of spirits separable from material bodies, and, as ghosts surviving bodily death, begin to take shape. Religion becomes spiritistic. The habit of making obeisance to the powerful or the clever, and of propitiating them, which has grown up step by step with leadership and personal government, is transferred to the realm of shades. Ghosts must be looked after and prayed to, or they might do mischief. Remembered, fed and honored, the kindred ghosts of a community are friendly, protecting powers. Religion becomes the bond of the living with the dead.

Through all these struggles, adaptations and adjustments, the fit that survive become in a degree socialized, and in the degree that they become social they become better assured of further survival. By the integration of small hordes of kindred into tribes, and the combination of

tribes into federations, ethnic society is evolved. The ghosts of tribal chieftains are supposed to be more powerful and important than ordinary ghosts; they enjoy, therefore, extraordinary honor and attention. They become gods. Religion becomes theistic.

The struggle for *existence* has now been won. The collective struggle for *advantage* begins. From every side confederated tribes of barbarian men press toward those regions that offer exceptional opportunities; such regions in early days were the shores and back country of the Caspian Sea, the valleys of the Euphrates and the Nile. This is the struggle for *situation*. Bringing together in one habitat a motley multitude of tribes, and fragments of shattered tribes, it grinds the tribal system to destruction. It assembles and mingles the human elements for an evolution of civil society.

When the struggle for place and opportunity has been won, and command of territory has been achieved, every energy is enlisted in the economic struggle for *abundance*. The new social order is not yet established. Miscellaneous men jostle each other, as in a mining camp. Each lives among his fellows on sufferance, or toleration. Society is merely approbational, and its interests are purely materialistic. The deities are gods of crops and generation.

This state of things, of course, can not last. The struggle for abundance begets the struggle for *efficiency*. Ideas and standards of efficiency appear. The efficient find each other out. They like each other and each other's ways. They dislike the inefficient, and begin in all possible ways to make life unpleasant for them. Efficiency and the habits that make therefor are identified with righteousness. The gods are credited with righteous impulses, and a desire to have men do right. Society has become congenial, and religion ethical.

The supreme struggle remains—the struggle for *supremacy*. To conquer, to dominate, to exploit—this alone can satisfy the state that has become strong enough to impose its yoke upon environing peoples. Armies are mustered and drilled, coercive rule and regimentation transform the domestic order. Society becomes despotic, and, since the gods of the conquerors must be worshipped by the conquered, religion becomes authoritative.

To show how despotic society breaks down, how in such frontier outposts as were the islands and shores of the Ægean Sea, intellect at last becomes dynamic, and political habit revolutionary, and how, under the hammering of these forces, society becomes contractual or constitutional, and religion rationalistic, would be to tell an enthralling story, for which no time remains. In one favored place, the Athenian city state, society became for a brief time idealistic, that is to say, its bonds were those of a common purpose, or ideal, and religion became non-theological. After two thousand years of arrest and slow recovery,

the cosmopolitan society of the western world is, possibly, once more approximating the Athenian model.

And the goal is what? If it be true, indeed, that through the ages an increasing purpose runs, is it made manifest in something that we may legitimately call progress? For progress, rightly defined, is more than evolution. It is race survival with individuation, or it is increasing individual power, capacity and happiness not entailing race extermination. Have we made sure of this? We hate to think ill of ourselves. Yet the question recurs: Has the survival of the fit become, at length, a survival of the best?

DARWIN'S INFLUENCE UPON PHILOSOPHY

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I

THAT the publication of the "Origin of Species" marked an epoch in the development of the natural sciences is well known to the layman. That the combination of the very words origin and species embodied an intellectual revolt and introduced a new intellectual temper is easily overlooked by the expert. The conceptions that had reigned in the philosophy of nature and knowledge for two thousand years, the conceptions that had become the familiar furniture of the mind, rested on the assumption of the superiority of the fixed and final; they rested upon treating change and origin as signs of defect and unreality. In laying hands upon the sacred ark of absolute permanency, in treating the forms that had been regarded as types of fixity and perfection as originating and passing away, the "Origin of Species" introduced a mode of thinking that in the end was bound to transform the logic of knowledge, and hence the treatment of morals, politics and religion.

No wonder then that the publication of Darwin's book, a half century ago, precipitated a crisis. The true nature of the controversy is easily concealed from us, however, by the theological clamor that attended it. The vivid and popular features of the anti-Darwinian row tended to leave the impression that the issue was between science on one side and theology on the other. Such was not the case—the issue lay primarily within science itself, as Darwin himself early recognized. The theological outcry he discounted from the start, hardly noticing it save as it bore upon the "feelings of his female relatives." But for two decades before final publication he contemplated the possibility of being put down by his scientific peers as a fool or as crazy; and he set, as the measure of his success, the degree in which he should affect three men of science: Lyell in geology, Hooker in botany and Huxley in zoology.

Religious considerations lent fervor to the controversy, but they did not provoke it. Intellectually, religious emotions are not creative but conservative. They attach themselves readily to the current view of the world and consecrate it. They steep and dye intellectual fabrics in the seething vat of emotions; they do not form their warp

and woof. There is not, I think, an instance of any large idea about the world being independently generated by religion. However much the ideas that rose up like armed men against Darwinism owed their intensity to religious associations, their origin and meaning are to be sought elsewhere.

II

Few words in our language foreshorten intellectual history as does the word species. The Greeks in initiating the intellectual life of Europe, were impressed by characteristic traits of the life of plants and animals; so impressed indeed that they made these traits the key to defining nature and to explaining mind and society. And truly life is so wonderful that a seemingly successful reading of its mystery might well lead men to believe that the key to the secrets of heaven and earth was in their hands. The Greek rendering of this mystery, the Greek formulation of the aim and standard of knowledge, was in the course of time embodied in the word species and controlled philosophy for two thousand years. To understand the intellectual face-about expressed in the phrase "Origin of Species," we must, then, understand the long dominant idea against which it was a protest.

Consider how men were impressed by the facts of life. Their eyes fell upon certain things slight in bulk, and frail in structure. To every appearance, these perceived things were inert and passive. Suddenly, under certain circumstances, these things—henceforth known as seeds or eggs or germs—begin to change, to change rapidly in size, form and qualities. Rapid and extensive changes occur, however, in many things—as when wood is touched by fire. But the changes in the living thing are orderly; they are cumulative; they tend constantly in one direction; they do not, like other changes, destroy or consume, or pass fruitless into wandering flux; they realize and fulfil. Each successive stage, no matter how unlike its predecessor, preserves its net effect and also prepares the way for a fuller activity on the part of its successor. In living beings changes do not happen as they seem to elsewhere, any which way; the earlier changes are regulated in view of later results. This progressive organization does not cease till there is achieved a true final term, a τελὸς, a completed, perfected end. This final form exercises in turn a plenitude of functions, not the least noteworthy of which is production of germs like those from which it took its own origin, germs capable of the same cycle of self-fulfilling activity.

But the whole miraculous tale is not yet told. The same drama is enacted to the same destiny in countless myriads of individuals so sundered in time, so severed in space, that they have no opportunity for mutual consultation and no means of interaction. As an old writer

quaintly said, "things of the same kind go through the same formalities"—celebrate, as it were, the same ceremonial rites.

This formal activity which operates throughout a series of changes and holds them to a single course; that subordinates their aimless flux to its own perfect manifestation; which, leaping the boundaries of space and time, keeps individuals in spite of their being distant in space and remote in time to a uniform type of structure and function: this principle seemed to give insight into the very nature of reality itself. To it Aristotle gave the name, εἶδος. This term the scholastics translated as *species.*

The force of this term was deepened by its application to everything in the universe that observes order in flux and manifests constancy through change. From the casual drift of daily weather, through the uneven recurrence of seasons and unequal return of seed time and harvest, up to the majestic sweep of the heavens—the image of eternity in time—and from this to the unchanging pure and contemplative intelligence beyond nature lies one unbroken fulfilment of ends. Nature, as a whole, is a progressive realization of purpose strictly comparable to the realization of purpose in any single plant or animal.

The conception of εἶδος, species, the fixed form and final cause, was the central principle of knowledge as well as of nature. Upon it rested the logic of science. Change as change is mere flux and lapse; it insults intelligence. Genuinely to know is to grasp a permanent end that realizes itself through changes, holding them thereby within the metes and bounds of fixed truth. Completely to know is to relate all special forms to their one single end and good: pure contemplative intelligence. Since, however, the scene of nature which directly confronts us is in change, nature as directly and practically experienced can not satisfy the conditions of knowledge. Human experience is also in flux, and hence the instrumentalities of sense-perception and of inference based upon observation are condemned in advance. Science is compelled to aim at realities lying behind and beyond the processes of nature, and to carry on its search for these realities by means of rational forms transcending ordinary modes of perception and inference.

There are, indeed, but two alternative courses. We must either find the appropriate objects and organs of knowledge in the mutual interactions of changing things; or else, to escape the infection of change, we *must* seek them in some transcendent and supernal region. The human mind, deliberately as it were, exhausted the logic of the changeless, the final and the transcendent, before it essayed adventure on the pathless wastes of generation and transformation. We dispose all too easily of the efforts of the schoolmen to interpret nature and mind in terms of real essences, hidden forms and occult faculties, forgetful of the seriousness and dignity of the ideas that lay behind. We

dispose of them by laughing at the famous gentleman who accounted for the fact that opium put people to sleep on the ground it had a dormitive faculty. But the doctrine, held in our own day, that knowledge of the plant that yields the poppy consists in referring the peculiarities of an individual to a type, to a universal form, a doctrine so firmly established that any other method of knowing was conceived to be unphilosophical and unscientific, was a survival of precisely the same logic. This identity of conception in the scholastic and anti-Darwinian theory may well suggest greater sympathy for what has become unfamiliar and greater humility regarding the further unfamiliarities that history has in store.

Darwin was not, of course, the first to question the classic philosophy of nature and of knowledge. The beginnings of the revolution are in the physical science of the sixteenth and seventeenth centuries. When Galileo said: "It is my opinion that the earth is very noble and admirable by reason of so many and so different alterations and generations which are incessantly made therein," he expressed the changed temper that was coming over the world; the transfer of interest from the permanent to the changing. When Descartes said: "The nature of physical things is much more easily conceived when they are beheld coming gradually into existence, than when they are only considered as produced at once in a finished and perfect state," the modern world became self-conscious of the logic that was henceforth to control it, the logic of which Darwin's "Origin of Species" is the latest scientific achievement. Without the methods of Copernicus, Kepler, Galileo and their successors in astronomy, physics and chemistry, Darwin would have been helpless in the organic sciences. But prior to Darwin the impact of the new scientific method upon life, mind and politics, had been arrested for the most part, because between these ideal or moral interests and the inorganic world there intervened the kingdom of plants and animals. The gates of the garden of life were barred to the new ideas while only through this garden was there access to mind and politics. The influence of Darwin upon philosophy resides in his having freed the new logic for application to mind and morals by conquering the phenomena of life. When he said of species what Galileo had said of the earth, *e pur se muove,* he emancipated once for all genetic and experimental ideas as an organon of asking questions and looking for explanations in philosophy.

III

The exact bearings upon philosophy of the new logical outlook are, of course, as yet, uncertain and inchoate. We live in the twilight of intellectual transition. One must add the rashness of the prophet to the stubbornness of the partisan to venture a systematic exposition of

the influence upon philosophy of the Darwinian method. At best, we can but inquire as to its general bearing—the effect upon mental temper and complexion, upon that body of half-conscious, half instinctive intellectual aversions and preferences which determine, after all, our more deliberate intellectual enterprises. In this vaguer inquiry there happens to exist as a kind of touchstone one problem of great historic significance that has also been much discussed in Darwinian literature. I refer to the old problem of design *versus* chance, mind *versus* matter, as the causal explanation, first and final, of things.

As we have already seen, the classic notion of species carried with it the idea of purpose. In all living forms, a specific type is present directing the earlier stages of growth to the realization of its own perfection. Since this purposive regulative principle is not visible to the senses, it follows that it must be an ideal or rational force. Since, however, the perfect form is gradually approximated through the sensible changes, it also follows that in and through a sensible realm a rational ideal force is working out its own ultimate manifestation. These two inferences were extended to nature: (*a*) She does nothing in vain; but all for an ulterior purpose. (*b*) Within natural sensible events there is therefore contained a spiritual causal force, which as spiritual escapes perception, but is apprehended by an enlightened reason. (*c*) The manifestation of this principle brings about a subordination of matter and sense to its own realization, and this ultimate fulfilment is the goal of nature and of man. The design argument thus operated in two directions. Purposefulness accounted for the intelligibility of nature and the possibility of science, while the absolute or cosmic character of this purposefulness gave sanction and worth to the moral and religious endeavors of man. Science was underpinned and morals authorized by one and the same principle, and their mutual agreement was eternally guaranteed.

This philosophy remained, in spite of sceptical and polemic outbursts, the official and the regnant philosophy of Europe for over two thousand years. The expulsion of fixed first and final causes from astronomy, physics and chemistry had indeed given the doctrine something of a shock. But, on the other hand, increased acquaintance with the details of plant and animal life made a counterbalance and perhaps even strengthened the argument from design. The marvellous adaptations of organisms to their environment, of organs to the organism, of unlike parts of a complex organ—like the eye—to the organ itself; the foreshadowing by lower forms of the higher; the preparation in earlier stages of growth for organs that only later had their functioning—these things were increasingly recognized with the progress of botany, zoology, paleontology and embryology. Together they added such prestige to the design argument that by the late

eighteenth century it was, as proved by the sciences of organic life, the central point of theistic and idealistic philosophy.

The Darwinian principle of natural selection cut straight under this philosophy. If all organic adaptations are due simply to constant variation and the elimination of those variations that are harmful in the struggle for existence which is brought about by excessive reproduction, there is no call for a prior intelligent causal force to plan and preordain them. Hostile critics charged Darwin with materialism and with making chance the cause of the universe.

Some naturalists, like Asa Gray, favored the Darwinian principle and attempted to reconcile it with design. Gray held to what may be called design on the instalment plan. If we conceive the "stream of variations" to be itself intended, we may suppose that each successive variation was designed from the first to be selected. In that case, variation, struggle and selection simply define the mechanism of "secondary causes" through which the "first cause" acts; and the doctrine of design is none the worse off because we know more of its *modus operandi.*

Darwin could not accept this mediating proposal. He admits or rather he asserts that it is "impossible to conceive this immense and wonderful universe including man with his capacity of looking far backwards and far into futurity as the result of blind chance or necessity."[1] But nevertheless he holds that since variations are in useless as well as useful directions, and since the latter are sifted out simply by the stress of the conditions of struggle for existence, the design argument as applied to living beings is unjustifiable; and its lack of support there deprives it of scientific value as applied to nature in general. If the variations of the pigeon, which under artificial selection give the pouter pigeon, are not preordained for the sake of the breeder, by what logic do we argue that variations resulting in natural species are pre-designed?[2]

IV

So much for some of the more obvious facts of the discussion of design *versus* chance as causal principles of nature and of life as a whole. We brought up this discussion, you recall, as a crucial instance. What does our touchstone indicate as to the bearing of Darwinian ideas upon philosophy? In the first place, the new logic outlaws, flanks, dismisses—what you will—one type of problems and substitutes for it another type. Philosophy forswears inquiry after absolute origins and absolute finalities in order to explore specific values and the specific conditions that generate them.

[1] "Life and Letters," Vol. I., p. 282; cf. 285.

[2] "Life and Letters," Vol. II., pp. 146, 170, 245; Vol. I., 283–84. See also the closing portion of his "Variations of Animals and Plants under Domestication."

Darwin concluded that the impossibility of assigning the world to chance as a whole and to design in its parts indicated the insolubility of the question. Two radically different reasons, however, may be given as to why a problem is insoluble. One reason is that the problem is too high for intelligence; the other is that the question in its very asking makes assumptions that render the question meaningless. The latter alternative is unerringly pointed to in the celebrated case of design *versus* chance. Once admit that the sole verifiable or fruitful object of knowledge is the particular set of changes that generate the object of study, together with the consequences that further flow from it, and no intelligible question can be asked about what, by assumption, lies outside. To assert—as is often asserted—that specific values of particular truths, social bonds and forms of beauty, if they can be shown to be generated by concretely knowable conditions, are meaningless and in vain; to assert that they are justified only when they and their particular causes and effects have all at once been gathered up into some inclusive first cause and some exhaustive final goal, is intellectual atavism. Such argumentation is reversion to the logic that explained the extinction of fire by water through the formal essence of aqueousness and the quenching of thirst by water through the final cause of aqueousness. Whether used in the case of the special event or in that of life as a whole, such logic only abstracts some aspect of the existing course of events in order to reduplicate it as a petrified eternal principle by which to explain the very changes of which it is the formalization.

When Henry Sidgwick casually remarked in a letter that as he grew older his interest in what or who made the world was altered into interest in what kind of a world it is anyway, his voicing of a common experience of our own day illustrates also the nature of that intellectual transformation effected by the Darwinian logic. Interest shifts from the wholesale essence back of special changes to the question of how these special changes serve and defeat concrete purposes; shifts from an intelligence that shaped things once for all to the particular intelligences which things are even now shaping; shifts from an ultimate goal of good to the direct increments of justice and happiness that intelligent administration of existent conditions may beget and that present carelessness or stupidity will destroy or forego.

In the second place, the classic type of logic inevitably set philosophy upon proving that life *must* really have certain qualities and values—no matter how experience presents the matter—because of some remote cause and eventual goal, while the logic of the new science frees philosophy from this apologetic habit and temper. The duty of wholesale justification inevitably accompanies all thinking that makes the meaning of special occurrences depend upon something that

lies once and for all behind them. The habit of derogating from present meanings and uses prevents our looking the facts of experience in the face; it prevents serious acknowledgment of the evils they present and serious concern with the goods they promise but do not yet fulfil. It turns thought to the business of finding a wholesale transcendent remedy for the one and guarantee for the other. One is reminded of the way many moralists and theologians greeted Herbert Spencer's recognition of an unknowable energy from which welled up the phenomenal physical processes without and the conscious operations without. Merely because Spencer labeled his unknowable energy "God," this faded piece of metaphysical goods was greeted as an important and grateful concession to the reality of the spiritual realm. Were it not for the deep hold of the habit of seeking justification for ideal values in the remote and transcendent, surely this reference of them to an unknowable absolute would be despised in behalf of the daily demonstrations of experience that knowable energies are daily generating about us precious values.

The displacing of this wholesale type of philosophy will doubtless not arrive by sheer logical disproof, but rather by growing recognition of its futility. Were it a thousand times true that opium produces sleep because of its dormitive energy, the inducing of sleep in the tired and the recovery to waking life of the poisoned, would not be thereby one least step forwarded. And were it a thousand times dialectically demonstrated that life as a whole is regulated by a transcendent principle to a final inclusive goal, truth and error, health and disease, good and evil, hope and fear in the concrete would remain none the less just what and where they now are. To improve our education, to ameliorate our manners, to advance our politics, we must have recourse to specific conditions of generation.

Finally, the new logic introduces responsibility into the intellectual life. To idealize and rationalize the universe at large is after all a confession of inability to master the courses of things that specifically concern us. As long as mankind suffered from this impotency, naturally it shifted a burden of responsibility which it could not carry over to the more competent shoulders of the transcendent cause. But if insight into specific conditions of value and into specific consequences of ideas is possible, philosophy must in time become a method of locating and interpreting the more serious of the conflicts that occur in life, and a method of projecting ways for dealing with them: a method of moral and political diagnosis and prognosis.

The claim to formulate *a priori* the legislative constitution of the universe is by its nature a claim that may lead into elaborate dialectic developments. But it is also one which removes these very conclusions from subjection to experimental test, for, by definition, these results

make no differences in the detailed course of events. But a philosophy that humbles its pretensions to the work of projecting hypotheses for the education and conduct of mind, individual and social, is thereby subjected to test by the way in which the ideas it propounds work out in practise. In having modesty forced upon it, philosophy also acquires responsibility.

Doubtless I may seem to have violated the implied promise of my earlier remarks and to have turned both prophet and partisan. But in anticipating the direction of the transformations in philosophy to be wrought by the Darwinian genetic and experimental logic, I do not profess to speak for any changes save those wrought in those who yield themselves consciously or unconsciously to this logic. No one can fairly deny that at present there are evident two effects of the Darwinian mode of thinking. On the one hand, there are making many sincere and vital efforts to revise our traditional philosophic conceptions in accordance with its demands. On the other hand, there is as definitely a recrudescence of absolutistic philosophies; an assertion of a type of philosophic knowing distinct from that of the sciences, which opens to us another kind of reality from that to which the sciences give access; an appeal through experience to something that radically transcends experiences. This reaction affects popular creeds and religious movements as well as technical philosophies. In other words, the very conquest of the biological sciences by the new ideas has led many to effect a more explicit and rigid separation of philosophy from science.

Old ideas give way slowly; for they are more than abstract logical forms and categories. They are habits, predispositions, deeply engrained attitudes of aversion and preference. Moreover, the conviction persists—though history shows it to be a hallucination—that all the questions that the human mind has asked are questions that can be answered in terms of the alternatives that the questions themselves present. But in fact intellectual progress usually occurs through sheer abandonment of such questions, together with both of the alternatives they assume—an abandonment that results from decreasing vitality and interest in their point of view. We do not solve them: we get over them. Old questions are solved by disappearing, evaporating, while new questions corresponding to the changed attitude of endeavor and preference take their place. Doubtless the greatest dissolvent of old questions, the greatest precipitant of new methods, new intentions, new problems, is the one effected by the scientific revolution completed in the "Origin of Species."

THE PROGRESS OF SCIENCE

THE COLLEGE AND THE STUDENT

At this commencement season university presidents and others are likely to make addresses to academic audiences and the problems of the college and of the college student are likely to be subjects for comment in the daily papers and the monthly magazines. This year two addresses have attracted special attention. Some rather incidental remarks of President Wilson, of Princeton University, are of intrinsic interest, and the Phi Beta Kappa address of President Lowell, of Harvard University, preceding his inaugural address, gives the first indication of his attitude toward questions concerning which his influence and responsibility are very great.

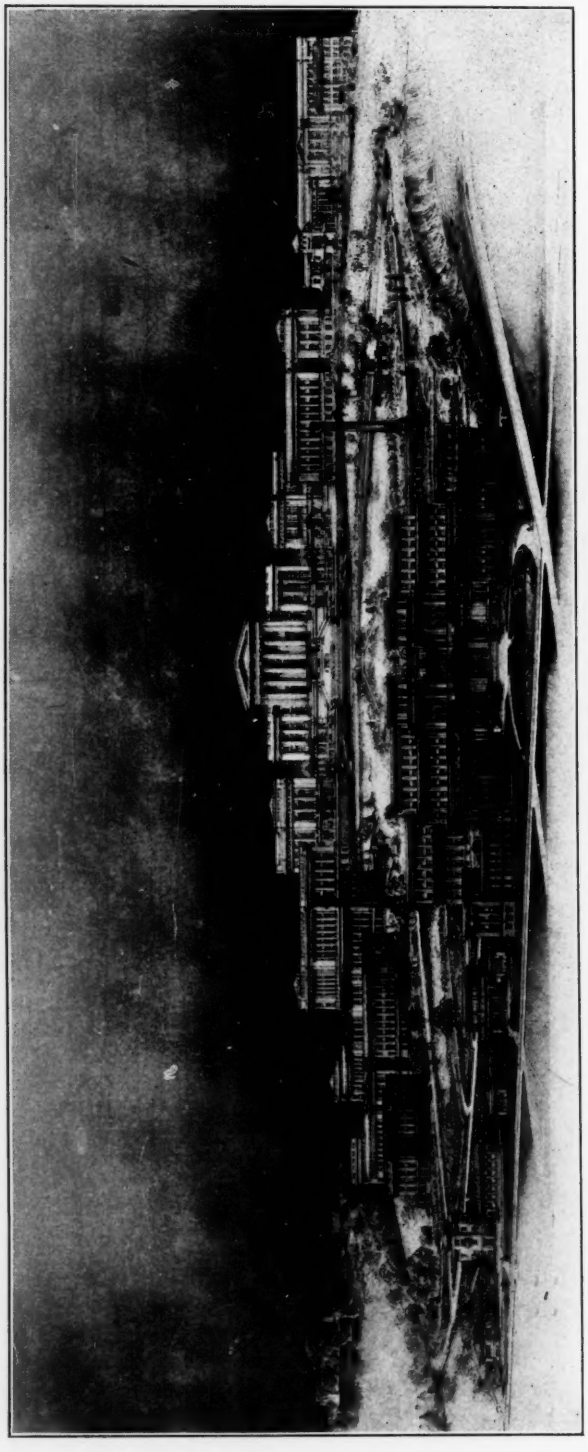
It is somewhat curious that the president of Princeton appears to be more modern in his point of view than the president of Harvard. President Wilson is reported as saying:

> I believe in athletics. I believe in all those things which relax energy that the faculties may be at their best when the energies are not relaxed, but only so far do I believe in these diversions. When the lad leaves school he should cease to be an athlete. The modern world is an exacting one, and the things it exacts are mostly intellectual.
>
> A danger surrounding our modern education is the danger of wealth. I am sorry for the lad who is going to inherit money. I fear that the kind of men who are to share in shaping the future are not largely exemplified in schools and colleges.
>
> So far as the colleges go, the sideshows have swallowed up the circus, and we in the main tent do not know what is going on. And I do not know that I want to continue under those conditions as ringmaster. There are more honest occupations than teaching if you can not teach.

This is characteristically well put, but the point of view is unexpected. It was supposed that the officers of Princeton were comparatively well satisfied with their rich boys, their professional athletics and their preceptorial system. It seems that on this occasion the president of Princeton is too iconoclastic and too pessimistic. The rich boys and the college boys will surely do more than the average in "shaping the future," even though this may be accomplished by a kind of monopoly control. The boy need not cease to be an athlete when he leaves the preparatory school; the trouble in our colleges is not that there are too many athletes, but too few, and those few over-trained and over-exploited. The college boy can do athletic stunts better than any one else can and better than he can do anything else; so there is much to be said for letting him do them. Satan can find worse mischief for idle hands.

When Mr. Wilson says that the things which the modern world exacts are mostly intellectual, he presumably refers to the kinds of things the Princeton preceptors try to teach. But what the world wants is men who will do the right thing at the right time. The boy who is to be a scholar in after life should be a scholar in college. But the average boy gains more from running the college paper or fraternity house than by writing Latin verses or even reading the innocuous literature prescribed by the College Entrance Examination Board. Certainly both college students and college teachers could be more usefully employed than they are at present; but it is odd that the president of Princeton should rub this in.

Mr. Lowell had undertaken to give the Phi Beta Kappa at Columbia before he was elected to the presidency of



PLAN OF THE UNIVERSITY OF PITTSBURGH.

Harvard. He was reported in the daily papers to have spoken in favor of inter-collegiate athletics and against the elective system. This would indeed be a cry of "le roi est mort," and explain why one seventh of the members of the Harvard corporation did not vote with the majority in the presidential election. As a matter of fact, Mr. Lowell spoke with skill and with caution. He did, however, argue that the elective system interferes with competition in college studies, and that the cooperative competition of athletic games should be applied to the work of the class room. But he did not tell how he thought that this could be accomplished. His main argument was from the competition in the English universities. He said: "The result is that by the Isis and the Cam there is probably more hard study done in subjects not of a professional character than in any other universities in the world." This is scarcely correct. The "poll" men at Oxford and Cambridge do even less work for their degrees than the average students at Harvard and Princeton. The men in the honor courses are doing professional work of much the same character as is done in the Harvard graduate and professional schools and with much the same rewards in the way of fellowships and positions. The greater direct competition in examinations which does obtain in the English universities is not necessarily an advantage. Indeed the arrangement of men in the order of merit in the mathematical tripos has just now been abandoned at Cambridge on the ground that it led to "cramming." Scholarship is more highly esteemed in England and in Germany (where there is no class-room competition in the universities) than here. Probably as time goes on there will be an equalization due to greater respect for the scholar here and to relatively higher regard for other forms of accomplishment there. Mr. Lowell said: "Universities stand for the eternal worth of thought, for the preeminence of the prophet and the seer." But the country can not support 80,000,000 prophets and seers.

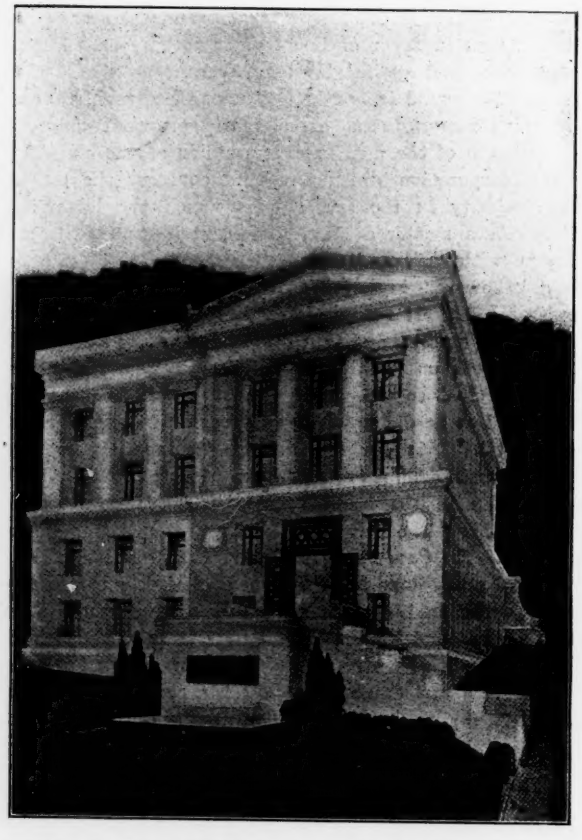
To one hearer Mr. Lowell's address seemed somewhat naïve, and left an impression of uncertainty as to how he would confront the complicated problems which the latter-day university president is expected to manage.

THE NEW BUILDINGS OF THE UNIVERSITY OF PITTSBURGH

In January, 1908, the University of Pittsburgh acquired a new location, consisting of 43 acres near the entrance to Schenley Park and within a short distance of the Carnegie Institute. The ground is partially rising and partially level, permitting an effective grouping of the buildings. Under the direction of Professor Warren P. Laird, an architects' competition was held in which sixty-six designs were submitted. The group plan accepted was that of Palmer & Hornbostel, a reproduction of which is here shown. The style of architecture is Grecian and is well adapted to the natural features of the ground. The location of the several departments of the university is determined and for the most part the exact buildings which will be erected.

The first building of the group, the School of Mines, is completed and has just been dedicated. Its cost is approximately $200,000. The second building, costing an equal sum, is in process of erection and will be ready for occupancy in September. The state appropriation provided by the last legislature permits the erection of another building, which will belong to the medical group. The architects are working upon the plans for this building, the erection of which will be commenced on July 1, permitting the medical department to begin its work in the new location in 1910.

As rapidly as buildings can be provided the other departments, law, dentistry and pharmacy will be transferred to the new location. The university



THE SCHOOL OF MINES BUILDING OF THE UNIVERSITY OF PITTSBURGH, the first to be erected on the new site.

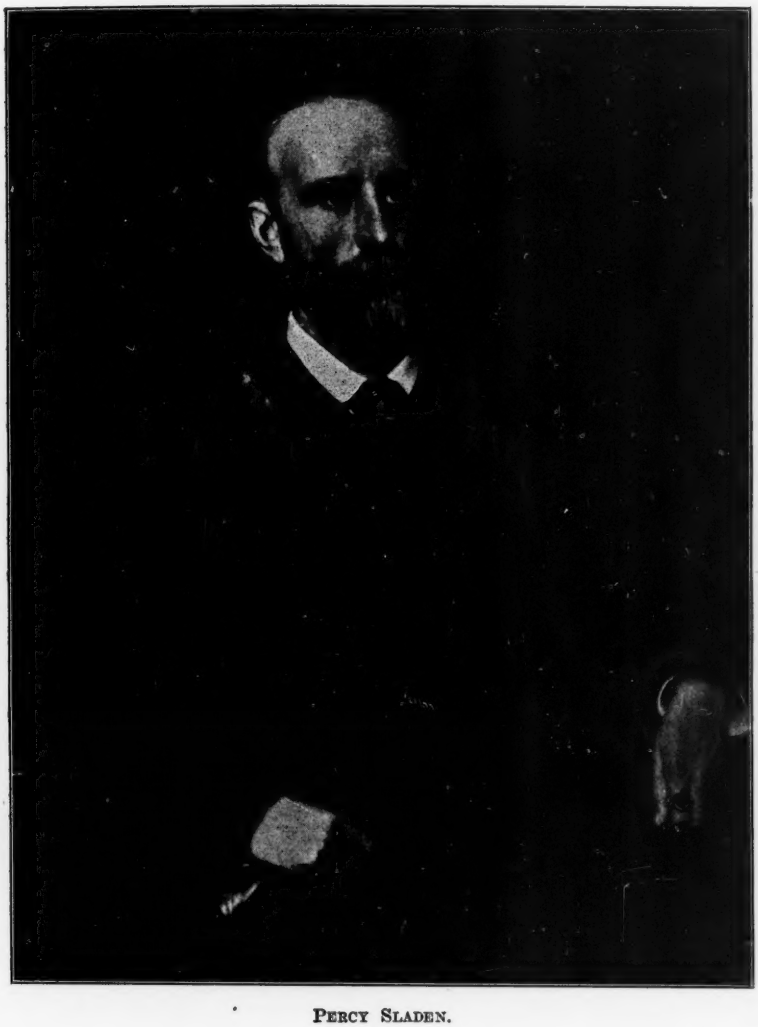
comprises the following departments: college, graduate, observatory, summer school, Saturday and evening classes, engineering, mining, medicine, dentistry, law and pharmacy.

The students in the regular classes during the past year have numbered 1,129. Those taking special work were 114, making a total of 1,243. The region in which the university is now located is remarkable because of the large number of fine buildings housing various educational and other institutions of the city. It bids fair to become one of the famous centers of the country.

The former buildings of the college and engineering school have been sold and the proceeds placed in the permanent fund of the university. During the past year nearly $300,000 have been raised by popular subscription. The first charter of the university was granted in 1787. The present year marks practically the first consolidation of the several departments under the absolute ownership and control of the university.

THE PERCY SLADEN MEMORIAL FUND

IN 1904 Mrs. Percy Sladen endowed with £20,000 a trust fund for the furtherance of research in the natural sciences in memory of her husband, who had died four years previously. The trustees of this fund, who are themselves men of science, are allowed



PERCY SLADEN.

wide discretion in its administration, but have adopted the policy of assisting expeditions. The first of these has been a zoological exploration of the Indian Ocean under the leadership of Mr. J. Stanley Gardiner, the results of which are now published in the *Transactions* of the Linnean Society of London. They fill a volume of 419 pages, the different groups of animals being worked over by leading specialists. The trustees of the fund are now supporting an anthropological expedition to Melanesia under the leadership of Dr. W. H. R. Rivers, and a third expedition will be sent to study the botany of West Africa, under Professor H. H. W. Pearson.

The volume containing the account of the expedition to the Indian Ocean is prefaced by an introduction on the life and work of Sladen by Mr. Henry Bury, with a portrait here reproduced from the painting by Mr. H. T. Wells, in the possession of the Linnean Society. Born in 1849, Sladen was educated at a public school where little or no attention was paid to science and

he did not attend a university. He became interested in science through the local scientific society and museum at Halifax, and received his training through them and through his own work. He accomplished scientific work of accuracy and importance, but was an amateur in the sense that he held no scientific position. Darwin is the most notable instance of the great contributions to science made in Great Britain by those having hereditary wealth and devoting their lives to scientific work, but he is only one of a large class, including men of great eminence, such as the two last presidents of the Royal Society, Lord Rayleigh and Sir William Huggins, and many others, such as Sladen, whose work may not be widely known, but is of a high class. It is to be hoped, though scarcely to be expected, that these traditions will be maintained in Great Britain and adopted here, as the number of our wealthy families increases.

Sladen concerned himself in the main with scientific work on the starfishes. In the course of twenty years he published thirty-five papers, the most extensive being the report on the Asteroidea collected by the *Challenger* which describes 184 new species. In an early paper he described an extraordinary form from a single specimen since lost which he placed in a new family intermediate between the Ophiurids and the Asterids. Another discovery of evolutionary interest was of certain "cribriform" organs in a family of starfishes. The function of these organs is not known; they appear in one family only with no indication as to how they may have been evolved, their number is fixed for each species, though it varies greatly within the family.

Though Sladen's scientific work was narrowly limited, he was a man of public spirit and wide accomplishments. He knew Persian as well as European literatures and was an expert collector and student of old books and manuscripts. He was zoological secretary of the Linnean Society and secretary of several committees of the British Association. His biographer says of him: "Cheerful, humorous and of a remarkably even temper, Sladen presented to his many friends a singularly lovable nature, in which unselfishness, sincerity and a generous appreciation of the work of others were some of the leading characteristics."

SCIENTIFIC ITEMS

WE record with regret the deaths of Dr. Georg von Neumayer, the eminent German meteorologist; of Dr. Wilhelm Engelmann, professor of physiology at Berlin, and of Dr. F. G. Yeo, F.R.S., the physiologist.

AMONG those who will have received an honorary degree from Cambridge University on the occasion of the Darwin centenary are three Americans: Professor Jacques Loeb, of the University of California; Dr. Charles D. Walcott, secretary of the Smithsonian Institution, and Professor E. B. Wilson, of Columbia University.

DR. IRA REMSEN, president of the Johns Hopkins University, has been elected president of the Society for Chemical Industry.—Dr. E. F. Nichols, professor of experimental physics at Columbia University, has been elected president of Dartmouth College.—Mr. Lazarus Fletcher, F.R.S., the keeper of the department of mineralogy since 1880, has been appointed to the post of director of the natural history departments of the British Museum.